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TAXATION, EMPLOYMENT AND THE ENVIRONMENT - GENERAL EQUILIBRIUM ANALYSIS WITH UNIONISED LABOUR MARKETS

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Abstract: We evaluate the effects of labour and environmental taxes in a general equilibrium model with unionised labour markets and involuntary unemployment. Environmental externality is related to the consumption of a polluting output. In particular, we examine whether a "double dividend" in terms of employment and the environment can be reaped with an environmentally motivated, revenue neutral tax reform. With unemployment benefits exempted from tax, we find that uncompensated increases in either labour income or environmental taxes lead to a lower equilibrium level of employment and polluting output. Numerical simulations with plausible parameter values show that employment will improve after the reform. The magnitude of the employment effect is considerable and depends positively on the share of polluting output in total consumption. However, due to the increased level of economic activity, environmental quality tends to deteriorate. This caveat can be avoided if tax cuts are targeted to the payroll tax in the non-polluting sector only. A prerequisite for the double dividend is that the elasticity of substitution between polluting and non-polluting consumption is large enough.

Keywords: Double dividend, environmental taxes, unemployment, general equilibrium

Tiivistelmä: Tutkimus käsittelee työvoima- ja ympäristöverojen vaikutuksia yleisen tasapainon mallissa, jossa ammattiliitto määrää palkat ja työttömyys on ei-vapaaehtoista. Ympäristöhaitta liittyy saastuttavan hyödykkeen kulutukseen. Keskeinen tutkimusongelma on, voidaanko nettokertymän säilyttävällä "vihreällä" veroreformilla saavuttaa ns. tuplapotti (double dividend) eli korkeampi työllisyys ja parempi ympäristön laatu. Mikäli työttömyyskorvausta verotetaan lievemmin, sekä työtulovero että ympäristövero vähentävät työllisyyttä ja ympäristöpäästöjä mallissa. Numeeriset simuloinnit osoittavat, että mahdollisilla parametriarvoilla veroreformi johtaa työllisyyden kasvuun. Työllisyysvaikutus on huomattava ja sen suuruus riippuu positiivisesti saastuttavan hyödykkeen kulutusosuudesta. Sen sijaan ympäristön laatu pyrkii kasvavan tuotannon myötä heikkenemään. Ongelma voidaan kiertää kohdistamalla verokevennykset yksinomaan "puhtaalle" tuotantosektorille laskemalla sektorikohtaista työnantajamaksua. Yleinen edellytys tuplapotin saavuttamiselle on, että hyödykkeiden substituutiojousto kulutuksessa on riittävän suuri.

Foreword

High and persistent unemployment in Finland and in the rest of Europe has lead to intensive debate on the role of labour taxation in exacerbating the unemployment problem. The Finnish debate has concentrated largely around the current medium term planning at the ministry of finance. At the same time, growing concern about the degradation of natural environment has increased the demand for enhanced environmental control with the means of, for example, environmental taxes. As the need to retain budgetary balance prevents any remarkable cuts in labour taxation, a natural solution seems to be to finance the revenue losses with a simultaneous increase in the environmental taxes. "Green tax reforms" of this kind have gained support in many European countries. At best, the restructuring of the tax system is hoped to produce a "double dividend": a simultaneous improvement in both employment and environmental quality. In reality, few large scale reforms have been undertaken and the evidence on the consequences is mixed.

Most of the earlier studies dealing with the issue of the double dividend are based on models with competitive labour markets. This study examines the possibility of a double dividend in a model framework that is consistent with the modern theories of the unionised labour markets. This enables the explicit inclusion of involuntary unemployment, a salient feature of the present economic reality. The results are tentative but encouraging in suggesting a positive employment effect of a revenue neutral switch from labour taxes to environmental taxes. However, the simultaneous achievement of both the employment and the environmental dividend seems less ensured.

The study contributes to the ongoing research project in VATT on the effects of taxation, social security and labour market policies on employment, growth and the public financial balance. The modelling framework introduced in this report will be developed further and utilised in the subsequent analysis in this field.

Helsinki, March 1999

Reino Hjerppe

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Helsinki, March 1999

Pekka Sinko

Summary

Since high labour taxes are considered one of the main causes of structural unemployment, there is a relatively large consensus holding that lowering the tax rates would improve employment. However, the simultaneous need to stabilise public debt has forced governments to seek alternative sources of revenue with less harmful effects in the labour market. In the recent discussion, emphasis has been put on the role of environmental taxes as the preferred instrument for raising revenues in the presence of other distortionary taxes. A revenue neutral shift in the tax mix in favour of environmental taxes is hoped to simultaneously reduce pollution and increase employment and thus to create a "double dividend".

The increased policy interest has inspired a number of theoretical and empirical studies to assess the possibility of a double dividend. Characteristic of this literature is mixed evidence and variety of different frameworks that makes the comparison of results somewhat difficult. Most of the earlier papers address the problem in a model with clearing labour markets. The basic findings are that in the single input models there are very limited possibilities for a double dividend. This is because environmental taxes tend be borne by labour, anyway. Allowing for input substitution increases the likelihood of a double dividend through the "tax burden shifting" effect: environmental taxes serve as a device to shift the tax burden to the relatively undertaxed factor.

It is well known that models based on clearing labour markets may give a seriously misleading picture of incidence and employment effects of taxes in economies with labour market distortions and involuntary unemployment. The high and relatively persistent involuntary unemployment of today's Europe obviously warrants a modelling framework that explicitly captures these observed features of the labour markets. The corner stone of tax policy analysis in such circumstances is plausible modelling of the wage formation process.

The most widely used structure for modelling the European labour markets is trade union models. In union models, wages depend on the reservation wage of the union members, which in turn depends on the unemployment benefits. Therefore, the level and taxation of unemployment benefits play a key role in the wage formation. On the other hand, as unemployment benefits are financed through tax revenues, changes in their volume should be taken into account when the effects of the tax policy on public deficit is evaluated.

Another distinctive feature of the existing literature is the concentration on the "second dividend", in other words, on employment effects. In most of the studies

the environmental "first dividend" is either ignored or taken for granted. The simultaneous consideration of both dividends is of particular interest, because there tends to be a trade-off between employment and environmental effects. Lower taxes on labour has a positive output effect that in most cases serves to increase pollution.

With these premises, this paper examines the effects of labour and environmental taxes in a general equilibrium framework allowing for imperfectly competitive labour markets and involuntary unemployment. The environmental externality is related to the consumption of a polluting output. Our modelling of labour markets consists of a centralised monopoly trade union confronting a constant elasticity labour demand by the firms employing two variable inputs, labour and capital. Institutional factors such as the financing of unemployment benefits by public revenues and their tax treatment are taken account of in the model.

With reference to the double dividend hypothesis, our specific interest is to examine whether employment and environment can be improved through an environmentally motivated restructuring of the tax system. In particular, we consider a revenue neutral switch from labour income tax to a consumption tax on the polluting output. We place emphasis on the achievement of the environmental as well as the employment dividend - an issue largely neglected in the existing literature. A numerical implementation of the model allows us to assess the magnitude of the effects and test their sensitivity to the values of the key parameters.

With unemployment benefits exempted or taxed at a lower rate than labour income, we find that uncompensated increases in either labour income or environmental taxes lead to a lower equilibrium level of employment and polluting output. Consequently, the effect on employment and the environment of a "green" tax reform that preserves the real level of public expenditure is a priori ambiguous. We show that for a double dividend to rise, the environmental tax has to raise more revenue per lost unit of employment and destroy more polluting output per unit of revenue raised than the labour income tax.

Our numerical simulations with plausible parameter values show that employment will indeed improve after the reform. The magnitude of the employment effect is considerable and depends positively on the share of polluting output in total consumption. With the baseline parameters, a ten percent increase in the environmental tax would cut the structural unemployment rate to roughly two thirds of its benchmark level, given that the revenue is recycled through a lower labour income tax. However, due to the increased level of economic activity, environmental quality tends to deteriorate. The achievement of an environmental dividend is less likely the higher is the share of polluting output in total consumption. This caveat can be avoided if tax cuts are targeted on the payroll tax of the non-polluting sector only. A prerequisite for the double dividend is that the elasticity of substitution between polluting and non-polluting consumption is large enough.

The results are broadly in line with the findings of earlier studies on the double dividend issue. In our setting, with unemployment benefits financed through taxes, the tax burden is not only shifted but also reduced after a reform that nonetheless leaves real public expenditure intact. This, together with a relatively large base for the environmental tax explains why the employment effects found in the model are large in comparison to the moderate effects reported in the earlier studies.

Our results emphasise that the second dividend cannot be taken for granted. This is the case in particular when the share of the polluting output in consumption is large. The policy implication is that checking out employment effects is simply not enough to justify a "green" reform. The sign and the magnitude of environmental effects must also be evaluated.

The present model is in many ways simplified and can hardly claim direct empirical relevance. The main purpose of the model is to clarify the mechanisms that drive the effects of environmental tax reform in an economy with unionised labour markets. The numerical simulation model also provides a basis for further research in terms of a more careful empirical assessment, where results from the recent econometric work related to the issue can be utilised. With only minor realignments the framework can be applied to other possible tax policy evaluation problems of current interest.

Yhteenveto

Korkeita työhön kohdistuvia veroja pidetään yleisesti keskeisenä rakenteellista työttömyyttä ylläpitävänä tekijänä. Niinpä onkin ilmeistä, että työhön kohdistuvia veroasteita alentamalla työllisyyttä voitaisiin kohentaa. Julkisen talouden tasapainottamistarve on kuitenkin useimmissa maissa pakottanut julkisen vallan etsimään muita, työllisyyttä vähemmän haittaavia veroja, joilla mahdolliset verokevennykset rahoitettaisiin. Viime aikojen keskustelussa on korostettu nimenomaan ympäristöverojen kykyä kerätä verotuloja pienemmin tehokkuus- ja työllisyystappioin kuin muut verot. On toivottu, että rahoittamalla työverojen alennus ympäristöveroja nostamalla, saavutettaisiin samanaikainen työllisyyden ja ympäristön laadun paraneminen eli "tuplapotti" (double dividend).

Päätöksentekijöiden lisääntynyt kiinnostus on synnyttänyt joukon teoreettisia ja empiirisiä tutkimuksia tuplapotti -kysymyksestä. Tunnusomaista tälle kirjallisuudelle ovat vaihtelevat tulokset sekä analyysikehikoiden kirjo, joka tekee tulosten vertailun jossain määrin vaikeaksi. Useimmat aikaisemmista tutkimuksista käsittelevät ongelmaa malleilla, joissa työmarkkinat ovat kilpailulliset. Perustulos on, että yhden panoksen tapauksessa tuplapotin saavuttaminen on varsin epätodennäköistä. Tämä johtuu siitä, että ympäristöverotkin pyrkivät siirtymään lopulta työvoiman kannettaviksi. Mikäli panossubstituutio työvoiman ja pääoman välillä otetaan huomioon, tuplapotin mahdollisuus kasvaa. Tällöin ympäristöverot voivat toimia välineenä, jolla verotaakkaa siirretään suhteellisesti lievemmin verotetulle panokselle, esimerkiksi pääomalle.

On yleisesti tunnettua, että kilpailullisiin työmarkkinoihin perustuvat mallit sopivat huonosti kuvaamaan taloutta silloin, kun työmarkkinat eivät toimi täydellisesti ja eivapaaehtoista työttömyyttä esiintyy. Mallien tuottama kuva verojen kohtaannosta ja työllisyysvaikutuksista on tällöin harhainen. Euroopassa vallitseva työmarkkinoiden neuvottelukäytäntö ja laajamittainen työttömyys vaativat näiden tekijöiden eksplisiittistä huomioon ottamista myös malleissa. Verojen vaikutusanalyysin kannalta keskeisessä roolissa on tällöin palkanmuodostuksen realistinen mallittaminen.

Eurooppalaisten työmarkkinoiden mallittamiseen ehkä parhaiten soveltuvan kehikon muodostavat ns. ammattiliittomallit. Ammattiliittomalleissa palkat riippuvat jäsenten reservaatiopalkasta, joka puolestaan riippuu mm. työttömyyskorvauksista. Näin ollen työttömyyskorvausten taso ja verokohtelu vaikuttavat olennaisesti palkanmuodostukseen. Toisaalta, koska työttömyyskorvaukset rahoitetaan verovaroin, niiden kokonaissumman muutokset on otettava huomioon arvioitaessa veropolitiikan vaikutuksia julkiseen rahoitustasapainoon.

Yksi aikaisempien tutkimusten tunnusomainen piirre on keskittyminen veroreformin työllisyysvaikutuksiin. Ympäristövaikutukset on joko jätetty huomiotta tai oletettu annetuiksi. Molempien vaikutusten samanaikainen tarkastelu on kuitenkin perusteltua, sillä ympäristö- ja työllisyysvaikutusten välille syntyy useissa tapauksissa valintatilanne: alhaisemmat työvoimaverot edistävät tuotannon kasvua, joka puolestaan pyrkii lisäämään päästöjä ja heikentämään ympäristön laatua.

Tässä tutkimuksessa tarkastellaan työvoima- ja ympäristöverojen vaikutuksia yleisen tasapainon mallissa, jossa monopolistinen ammattiliitto asettaa palkat ja sen seurauksena syntyy ei-vapaaehtoista työttömyyttä. Hyödykemarkkinoilla kilpailulliset yritykset tuottavat puhtaita ja saastuttavia hyödykkeitä käyttäen kahta panosta, työvoimaa ja pääomaa. Saastuttavien hyödykkeiden kuluttaminen aiheuttaa ympäristön pilaantumista. Työttömyyskorvausten verokohtelu ja niiden rahoittaminen verokertymän kautta otetaan mallissa huomioon.

Edellä mainittuun" tuplapotti" -problematiikkaan liittyen tutkimuksessa tarkastellaan erityisesti "vihreän" veroreformin vaikutuksia: voidaanko työvoimaverojen alentaminen kompensoida ympäristöveroja nostamalla niin, että sekä työllisyys ja ympäristön laatu paranevat, mutta julkiset nettoverotulot säilyvät ennallaan? Tutkimuksessa kiinnitetään erityistä huomiota paitsi työllisyyteen myös ympäristövaikutuksiin, jotka ovat aiemmassa tutkimuksessa jääneet vähemmälle huomiolle. Mallin numeerinen versio mahdollistaa vaikutusten suuruusluokkien arvioinnin ja tulosten herkkyyden testaamisen avainparametrien suhteen.

Tulosten mukaan, mikäli työttömyyskorvauksia ei verota tai verotetaan lievemmin kuin työtuloja, sekä työtulovero että ympäristövero heikentävät työllisyyttä ja parantavat ympäristön laatua. Näin ollen vihreän veroreformin vaikutus työllisyyteen ja ympäristön laatuun on a priori epäselvä. Tutkimuksessa osoitetaan, että "tuplapotin" saavuttamiseksi ympäristöverolla on pystyttävä keräämään enemmän verotuloja menetettyä työpaikkaa kohti ja syrjäyttämään enemmän saastuttavaa tuotantoa veromarkkaa kohden kuin työtuloverolla.

Tyylitellyillä parametriarvoilla tehdyt numeeriset simuloinnit osoittavat, että vihreä veroreformi parantaa työllisyyttä mallissa. Työllisyysvaikutus on huomattava ja riippuu positiivisesti saastuttavan hyödykkeen osuudesta kulutuksessa. Kymmenen prosentin energiaveron korotus, jonka kertymä käytetään työtuloveron alentamiseen, alentaa perusparametriarvoilla työttömyysastetta noin kahteen kolmannekseen perusvuoden tasostaan. Kuitenkin, koska tuotanto kasvaa, ympäristön laatu pyrkii heikkenemään. Ympäristön laadun paraneminen on sitä epätodennäköisempää, mitä korkeampi on saastuttavan hyödykkeen osuus kulutuksesta. Tämä ongelma voidaan välttää kohdistamalla verohuojennus yksinomaan "puhtaille" toimialoille eli porrastamalla työvoiman panosvero päästöjen suhteen. Tällöinkin "tuplapotin" edellytyksenä on, että saastuttavalle kulutukselle on tarjolla riittävän läheisiä vähemmän saastuttavia substituutteja.

Tutkimuksen tulokset ovat laajasti ottaen linjassa aikaisempien tulosten kanssa. Käytetyssä mallissa, jossa työttömyyskorvaus rahoitetaan verokertymästä, verotaakka ei ainoastaan siirry lievemmin verotetulle pääomalle vaan myös pienenee työllisyyden elpyessä. Julkisen sektorin nettotulot ja reaaliset menot poislukien työttömyyskorvaukset säilyvät ennallaan. Tämä mekanismi yhdessä melko laajapohjaisen ympäristöveron kanssa selittävät miksi työllisyysvaikutukset ovat jonkin verran suurempia kuin aikaisemmissa arvioissa on esitetty.

Tulokset korostavat, että ympäristön laadun kohoamista reformin seurauksena ei voida pitää itsestäänselvänä. Näin erityisesti silloin, kun saastuttavan kulutuksen osuus on suuri. Politiikan näkökulmasta tämä merkitsee, että yksinomaan työllisyysvaikutusten arvioiminen ei riitä perustelemaan "vihreää reformia". Myös ympäristövaikutuksen suunta ja suuruus on pyrittävä selvittämään.

Tutkimuksessa käytetty malli on monessa suhteessa pelkistetty eikä sillä välttämättä ole suoraa empiiristä relevanssia. Mallin ensisijainen tehtävä on valottaa niitä mekanismeja, jotka ohjaavat ympäristöveroreformin vaikutuksia taloudessa, jossa ammattiliitot vaikuttavat palkanmuodostukseen. Mallin numeerinen versio tarjoaa puolestaan hyvän lähtökohdan yksityiskohtaisemmalle empiiriselle työlle, jossa voidaan hyödyntää aihepiiriin liittyvää tuoretta ekonometristä tutkimusta. Samaa mallikehikkoa voidaan vain vähäisillä muutoksilla soveltaa myös muiden ajankohtaisten verokysymysten tarkasteluun.

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1. Introduction

Total tax revenue relative to GDP grew rapidly in the 90's in Finland.[1] At the same time unemployment became the major economic problem with unemployment rate peaking at 18 per cent in 1994. A major part of the upsurge in unemployment can be attributed to the great depression and the consequent 13 per cent drop in the real GDP between 1991 and 1993. However, the sluggish recovery of the employment after the depression has led to growing concern that part of the increased unemployment has become structural in nature. Generally, high labour taxes are considered one of the main causes of structural unemployment.

The relationship between employment and taxation has been in the focus of several studies initiated by the Finnish ministry of finance. VATT (1998) reviews the effects of taxation on employment, investment and output. Tossavainen (1998) considers the effects of labour and energy taxation on employment and investment. Honkapohja et al (1999) confines to the employment effects of labour taxation. These studies, based on partial equilibrium framework, find moderate positive employment effects for lower labour taxes. Holm et al (1999a,b) analyse the effect of labour taxation in an applied job flow model with comparable results.

Thus, there is a relatively large consensus holding that lowering tax rates would help to improve employment. However, the simultaneous need to stabilise public debt has forced the government to seek alternative sources of revenue with less harmful effects in the labour market. In recent discussion, emphasis has been put on the role of environmental taxes as the preferred instrument for collecting revenues in the presence of other distortionary taxes. A shift in the tax mix in favour of environmental taxes is expected to simultaneously reduce pollution and increase employment and thus to create a "double dividend"[2] (e.g. European Economy, 1994,

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[1] The rate of 46 per cent in 1995 was well above the EU average of roughly 40 per cent (VATT, 1998).

[2] The term double dividend refers to a simultaneous improvement in environmental quality and employment or economic efficiency. For a survey and alternative definitions, see Goulder (1995).

Commission Européenne, 1997, OECD, 1997). Reflecting the governments' budget constraints, the presumption is that such a reform should leave tax revenues intact.

The increased policy interest has inspired a number of theoretical and empirical studies to assess the possibility of a double dividend. An early survey of the problems involved is provided by Goulder (1995). A more recent taxonomy of the existing studies can be found in Carraro et al (1996). Characteristic of the literature is the mixed evidence and the variety of different frameworks that makes a comparison of the results somewhat difficult. The main variation in frameworks concerns the structure of labour market, input substitution, the openness of the economy, sources of pollution and institutional aspects such as the degree of centralisation in the wage formation and the taxation of unemployment benefits. In addition, some studies focus on the derivation of optimal tax policies whereas others take up the "tax reform" viewpoint and consider the effects of tax policy changes starting from a given initial tax system. A new aspect in the double dividend literature is the inclusion of employment as an additional objective for tax design.

One of the key differences between the studies is the assumption concerning the workings of the labour market. Most earlier papers address the problem in a model with clearing labour markets. The basic findings are that in the single input models there are very limited possibilities for a double dividend (e.g. Bovenberg & de Mooij, 1994, Bovenberg & van der Ploeg, 1994a). Bovenberg and van der Ploeg (1994b) show within a small open economy framework that this result carries over to multiple inputs as long as the prices of inputs other than labour are exogenous. Generally, allowing for input substitution increases the odds of a double dividend through the "tax burden shifting"[3] effect: environmental taxes can serve as a device for shifting the tax burden to a relatively undertaxed factor (e.g. Goulder, 1995, Sinko, 1996 and de Mooij & Bovenberg, 1998).

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3 For discussion of the topic see Bovenberg & Goulder (1997).

It is well known that models involving clearing labour markets may give a seriously misleading picture of tax incidence and employment effects in economies where labour market distortions exist and where involuntary unemployment is likely to arise. The high and relatively persistent involuntary unemployment of our day seems to warrant a modelling framework that explicitly captures such observed features of the labour markets. Recently, several attempts have been made to analyse the double dividend issue in models with non-clearing labour markets.

Generally, the models involving non-competitive labour markets tend to favour the possibility of a double dividend relative to those based on labour market clearing. Bovenberg and van der Ploeg (1996) apply a model where unemployment arises due to an exogenously fixed consumer wage. With externalities related to a polluting input, they find that if the pre-existing environmental tax is low, employment may increase, given that substitution between labour and the polluting input is large enough. Similar results are found by Koskela et al (1998) when applying a model with wage bargaining in the labour markets. Holmlund and Kolm (1997) employ an open economy model incorporating tradable and non-tradable sectors and sector specific unions. They find a positive employment effect conditional on a wage premium in the tradable sector.

An alternative approach to environmental externalities is to assume that pollution is related to the consumption of the outputs rather than the use of polluting resources as inputs. Bovenberg & de Mooij (1994) is the single input and clearing labour market case with pollution and environmental taxes related to consumption. Koskela and Schöb (1997) apply a model incorporating wage bargaining and single input technology. Contrary to Bovenberg and de Mooij, they find that employment may improve after a revenue neutral "green" reform. However, as Koskela and Schöb point out, results depend on institutional aspects such as indexation and taxation of unemployment benefits.

A distinctive feature of the existing literature is the concentration on the "second dividend", in other words, on employment effects. In most of the studies the environmental "first dividend" is either ignored or taken for granted. The simultaneous consideration of both dividends is of particular interest, because there tends to be a trade-off between employment and environmental effects. Lower taxes on labour has a positive output effect that in most cases serves to increase pollution. A recent contribution along these lines is that of Bayindir-Upmann and Raith (1997), who find that if the share of polluting consumption and the initial tax rate on labour are high, increased employment will lead to a deterioration of the environment.

This study examines the effects of labour and environmental taxes in a general equilibrium model with non-clearing labour markets. Unemployment is due to a monopoly trade union driving the wage rate above the market clearing level. Along with Bovenberg & de Mooij (1994) and Koskela & Schöb (1997), we assume that environmental damage is caused by the consumption of a polluting good.[4] However, we extend their framework by allowing for an input substitution between labour and capital, both fully mobile across sectors of production. We also allow for centralised wage formation[5] and for a consistent treatment of unemployment benefits as being financed with public revenues. Besides labour income tax, we consider the effects of a sector specific payroll tax on labour input.[6] Throughout the analysis, we adopt the viewpoint of a tax reform considering the effects of tax policy changes on the key variables rather than trying to derive optimal policies.

Following Bayindir-Upmann and Raith (1997), we place emphasis on the achievement of the environmental as well as the employment dividend - an issue largely neglected in the existing literature. As an extension of their analysis, we show that

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[4] With clearing output markets this is equivalent to assuming that pollution related to production of the good is independent of the input mix used.

[5] Most of the existing literature with non-clearing labour markets assume decentralised unions, which to some extent understates the perception of economic aggregates by unions in fairly centralised bargaining systems such as those in the Nordic countries (see e.g. Calmfors, 1993).

[6] Employment effects of sector specific payroll taxes in unionised labour markets has been analysed e.g. by Kolm (1998).

the elasticity of substitution between polluting and non-polluting consumption plays a role in determining the effects of a "green" tax reform. Besides qualitative results, a numerical implementation of the model allows us to assess the magnitude of the effects and test their sensitivity to the values of the key parameters. The numerical model also provides a framework that can be developed into an empirical simulation model for tax policy evaluation.[7]

The results are broadly in line with the findings of earlier studies on the double dividend issue. As is typical in non-clearing labour market models, we find a potentially positive employment dividend due to increased wage moderation. Qualitatively the employment effects are similar to those derived in a single input framework by Koskela & Schöb (1997) and partial equilibrium calculations by Tossavainen (1998). They are also in line with the findings of Sinko (1996) in a two factor model with clearing labour markets. In our setting, with unemployment benefits financed through taxes, the tax burden is not only shifted but also reduced after a reform that nonetheless leaves real public expenditure intact. This, together with a relatively large base for the environmental tax explains why the employment effects found in the model are larger than the moderate effects reported in some of the earlier studies (e.g. OECD, 1997 and Honkatukia, 1997). However, the positive employment effect tends to undermine the environmental goals of the reform.

The structure of the paper is as follows: Section 2 presents the model structure and derives the supply and demand equations from the optimisation problems of individual consumers and firms. The general equilibrium solution with an exogenous wage rate is derived in section 2.4. Section 2.5 endogenises the wage formation through the introduction of a monopoly union structure within the labour markets. Section 3.1 presents comparative statics results of uncompensated changes in the tax rates on the labour income and the polluting output. Section 3.2 derives corresponding results for the sector specific payroll tax. Section 4 discusses revenue

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7 The double dividend problem has been analysed in empirical simulation models by e.g. Carraro et al (1996) for EU, SOU (1997) for Sweden and Honkatukia (1997) for Finland.

preserving calculations and presents some results on the effects of a revenue neutral "green" tax reform. Numerical simulations are presented in section 5. The conclusions will be drawn in section 6. Detailed derivation of the key equations and some supplementary results are presented in the appendices.

2. The Model

To analyse environmental tax reform in a general equilibrium framework, we specify a simple model where production takes place in two competitive sectors, each utilising two primary inputs - labour and capital. The output of the other sector is assumed to have an adverse effect on environment. Demand for the two outputs is derived from the utility maximising problem of three groups of consumers - those employed in one of the sectors, and those unemployed. Government levies indirect taxes on the consumption of the two outputs, and direct taxes on incomes from the primary factors. Tax receipts are used to finance unemployment benefits and other transfers to households. Wages are set by a centralised monopoly trade union and employment is determined by the firms' demand.

In this section we first derive the behavioural equations of firms and consumers given the structure of government tax and transfer policies. We then derive the general equilibrium with exogenous wage rate and consider the effects of exogenous changes in the wage rate. Finally, we endogenise wage formation by the introduction of a monopoly union structure into the labour market.

2.1 Producer Behaviour

We assume that there are two production sectors in the economy, the non-polluting C-sector and the polluting D-sector. Each sector consists of a fixed number of homogenous competitive firms producing one output.[8] The firms employ unitary elasticity of substitution technology with two inputs, labour and capital and decreasing returns to scale.[9] The problem of a competitive firm in sector i=C,D is then to choose an input bundle so as to maximise profits

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[8] A fixed number of firms amounts to assuming no free entry for firms, which allows for positive profits in the equilibrium.

[9] The unitary elasticity technology (or Cobb-Douglas technology) is widely used for analytical tracta-

$$\Pi_i = q_i \Omega_i L_i^{\alpha_i} K_i^{\beta_i} - q_{Li} L_i - q_k K_i \tag{2.1}$$

where $\Omega_i, \alpha_i, \beta_i > 0, \alpha_i + \beta_i < 1$ are production function parameters, q_i is producer price of output i=C,D, q_k is producer price of capital input and q_{Li} is the producer price of labour in sector i. After some manipulation (see Appendix 1 for details) this yields the input demands

$$L_i = \Omega_{Li}\left[q_i q_k^{-\beta_i} q_{Li}^{-(1-\beta_i)}\right]^{1/\Delta_i}$$
$$K_i = \Omega_{Ki}\left[q_i q_k^{-(1-\alpha_i)} q_{Li}^{-\alpha_i}\right]^{1/\Delta_i} \tag{2.2}$$

where $\Delta_i = 1 - \alpha_i - \beta_i$, $\Omega_{Li} = \left(\Omega_i \alpha_i^{1-\beta_i} \beta_i^{\beta_i}\right)^{1/\Delta_i}$ and $\Omega_{Ki} = \left(\Omega_i \alpha_i^{\alpha_i} \beta_i^{1-\alpha_i}\right)^{1/\Delta_i}$ are positive constants depending on the production function parameters. Sectoral input demands are found by simply multiplying firm level demands by the number of firms in each sector.

Substituting the input demands given by (2.2) into the production function and multiplying by the number of firms in sector, n_i, i=C,D, yields output supply functions in terms of the input and output prices

$$Y_i = \Lambda_i\left[q_i^{\alpha_i+\beta_i} q_{Li}^{-\alpha_i} q_k^{-\beta_i}\right]^{1/\Delta_i} \tag{2.3}$$

where Y_i , i=C,D refers to output supply of the two sectors respectively and $\Lambda_i = \left[\Omega_i \alpha_i^{\alpha_i} \beta_i^{\beta_i}\right]^{1/\Delta_i}$ is a positive constant depending on the production function parameters. Finally, substituting (2.2) into (2.1) yields the profit function

$$\Pi_i = \Delta_i \Lambda_i\left[q_i q_{Li}^{-\alpha_i} q_k^{-\beta_i}\right]^{1/\Delta_i} \tag{2.4}$$

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bility. However, it imposes strong restrictions on the technology that are not in line with the empirical evidence (see e.g. Hamermesh, 1993). We can consider there being a (sector specific) fixed factor causing decreasing returns with respect to the variable inputs. Profits can then be interpreted as return on the fixed factor e.g. some energy resource.

which defines the profit of an individual firm as a function of output and input prices (e.g. Varian, 1984). Sectoral inputs, outputs and profits are found by simply multiplying the right hand sides of (2.2), (2.3) and (2.4) by the number of firms in each sector. For ease of exposition, we normalise the number of firms in each sector to unity. In what follows, we further assume that technology is equal across sectors.[10]

2.2 Taxes and Transfers

We assume government levies payroll taxes on labour, taxes on labour and capital income and consumption taxes on the two goods. Government expenditure consists of unemployment benefits and general income transfers to consumers. Thus, government budget becomes

$$s_c w L_c + s_d w L_d + t_l w(L_c + L_d) + t_k q_k (K_c + K_d) + t_c q_c Y_c + t_d q_d Y_d = TR + B \qquad (2.5)$$

where t_i for i=C,D is a consumption tax levied on the producer such that

$$p_i = (1 + t_i) q_i . \qquad (2.6)$$

where p_i is consumer price and q_i is producer price of output i. For capital, t_k is an income tax levied on consumer such that

$$p_k = (1 - t_k) q_k \qquad (2.7)$$

where p_k is consumer price and q_k is producer price of capital. For labour, t_l is an income tax levied on consumer such that

[10] The assumption of equal technology (e.g. Bovenberg & de Mooij, 1994 and Koskela & Schöb, 1998) allows us to abstract from the effects related to different factor intensities in production of the two output categories. The implications of different factor intensities are discussed by e.g. Goulder (1995) and Sinko (1996).

$$p_L = (1 - t_l)w \tag{2.8}$$

and s_i is a sector specific payroll tax such that

$$q_{Li} = (1 + s_i)w \tag{2.9}$$

where p_L is consumer price of labour, q_{Li} is the producer price of labour in sector i and w is the net wage. In the case $s_c=s_d=s$, producer price of labour will be equal across sectors. On the right hand side of (2.5), TR is the total value of general income transfers and B is the total amount of unemployment benefits given by

$$B = b_n[M - (L_c + L_d)] \tag{2.10}$$

where $b_n = bp$ is the unemployment benefit, M is the total number of consumers entitled to benefits if unemployed.

2.3 Consumer Behaviour

We assume a fixed number of consumers, M, that receive factor income from hours of work, hired capital and firms' profits. In addition, government pays consumers unemployment benefits and other transfers. We can distinguish between three types of consumers according to their position in the labour market. All consumers are either employed in one of the two production sectors or unemployed. Assuming each individual supplies one unit of labour, the budget constraint of those employed is given by

$$p_c C_i + p_d D_i = p_L + p_k k_i (K_c + K_d) + v_i(\Pi_c + \Pi_d) + r_i TR \tag{2.11}$$

where C_i and D_i are the quantities of outputs consumed by a consumer employed in sector i=C,D, p_L is the consumer wage, k_i is the share of capital endowment of a consumer employed in sector i, v_i is the profit share and r_i the share of transfers other than unemployment benefits of consumers employed in sector i. The budget constraint of those unemployed is given by

$$p_c C_u + p_d D_u = b_n + p_k k_u (K_c + K_d) + v_u (\Pi_c + \Pi_d) + r_u TR \qquad (2.12)$$

where C_u and D_u are the quantities of outputs consumed by an unemployed consumer, k_u is the share of capital endowment of an unemployed consumer, s_u is the profit share and r_u the transfer share of an unemployed consumer. In what follows, we assume that the individual's share of profits and other transfers and capital endowment do not depend on their position in the labour market. In other words, k_j= $v_j = r_j$ =1/M for all types of consumers j=C,D,U.

Assuming that preferences do not change as one's position in labour market changes, we define a utility function common to all consumers

$$U_j = \left[\delta C_j^{\gamma} + (1-\delta) D_j^{\gamma}\right]^{1/\gamma} + u(E), \gamma \leq 1, u' > 0 \qquad (2.13)$$

where u is a separable subutility function on environmental quality, E. To allow for environmental effects, we assume a negative dependence between the level of polluting output consumed[11] and environmental quality, $E = e[D], e' < 0$. As the environment enters private utility in a separable manner, the precise form of function e is not important for our purposes.

The problem for a representative consumer is to choose a consumption bundle so as to maximise (2.13) subject to (2.11) or (2.12). Making the usual assumption of a single consumer ignoring the effect of their consumption on the environment yields the first order condition (see appendix 2 for details)

[11] With clearing output markets, whether pollution is caused by production or consumption of the output does not make any difference as long as the amount of pollution emitted is independent of the input mix used. For an alternative approach involving substitution between polluting and non-polluting inputs see e.g. Bovenberg and van der Ploeg (1996).

$$C_j/D_j = \left[\frac{\delta p_d}{(1-\delta)p_c}\right]^{\sigma} \tag{2.14}$$

where $\sigma = 1/(1-\gamma)$ is the elasticity of substitution between the two consumption goods. Substituting (2.14) in (2.11) or (2.12) yields the following demands of representative consumers for the two goods

$$C_j = \delta^{\sigma}\left(\frac{p_c}{p}\right)^{1-\sigma}\frac{m_j}{p_c}$$

$$D_j = (1-\delta)^{\sigma}\left(\frac{p_d}{p}\right)^{1-\sigma}\frac{m_j}{p_d} \tag{2.15}$$

where m_j , j= c,d,u denotes the income of the consumer given by the right hand side of (2.11) or (2.12) and taken as given by a individual consumer. Further,

$$p = \left[\delta^{\sigma}p_c^{1-\sigma} + (1-\delta)^{\sigma}p_d^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{2.16}$$

is the ideal consumer price index (see appendix 2 for derivation of the CPI). Aggregate demands can be derived by adding up the demands of representative consumers. For the non-polluting output we get

$$C = L_cC_c + L_dC_d + (M - L_c - L_d)C_u = \delta^{\sigma}\left(\frac{p_c}{p}\right)^{1-\sigma}\frac{m}{p_c} \tag{2.17}$$

and for the polluting output,

$$D = L_cD_c + L_dD_d + (M - L_c - L_d)D_u = (1-\delta)^{\sigma}\left(\frac{p_d}{p}\right)^{1-\sigma}\frac{m}{p_d} \tag{2.18}$$

where

$$m = L_cm_c + L_dm_d + (M - L_c - L_d)m_u \tag{2.19}$$

is the aggregate consumer income. Substituting the right hand side of the budget constraints (2.11) and (2.12) for the incomes of the representative consumers and rearranging yields

$$m = p_L(L_c + L_d) + p_k(K_c + K_d) + (\Pi_c + \Pi_d) + TR + B \tag{2.19'}$$

To derive a more convenient expression for consumer aggregate income, we substitute (2.5) for transfers and (2.1) for profits in (2.19'). Rearranging yields

$$m = (1 + t_c)q_c Y_c + (1 + t_d)q_d Y_d \tag{2.20}$$

reflecting the fact that all the income created in production is returned to consumers. Substituting (2.3) for the output supplies and invoking the assumption of symmetric technology yields

$$m = \Lambda w^{-\alpha/\Delta} q_k^{-\beta/\Delta}\left[(1 + t_c)(1 + s_c)^{-\alpha/\Delta} q_c^{1/\Delta} + (1 + t_d)(1 + s_d)^{-\alpha/\Delta} q_d^{1/\Delta}\right] \tag{2.21}$$

Now recalling consumer aggregate demands for the two outputs given by (2.17) and (2.18) and substituting (2.21) for income and (2.16) for the consumer price index and converting to producer prices we get

$$\begin{aligned} C &= \delta^\sigma \Lambda (1 + t_c)^{-\sigma} q_c^{-\sigma} w^{-\alpha/\Delta} q_k^{-\beta/\Delta} I_1 I_2 \\ D &= (1 - \delta)^\sigma \Lambda (1 + t_d)^{-\sigma} q_d^{-\sigma} w^{-\alpha/\Delta} q_k^{-\beta/\Delta} I_1 I_2 \end{aligned} \tag{2.22}$$

where I_1 and I_2 are price indices such that

$$\begin{aligned} I_1 &= \left[(1 + t_c)(1 + s_c)^{-\alpha/\Delta} q_c^{1/\Delta} + (1 + t_d)(1 + s_d)^{-\alpha/\Delta} q_d^{1/\Delta}\right] \\ I_2 &= \left[\delta^\sigma (1 + t_c)^{1-\sigma} q_c^{1-\sigma} + (1 - \delta)^\sigma (1 + t_d)^{1-\sigma} q_d^{1-\sigma}\right]^{-1} \end{aligned} \tag{2.23}$$

Thus (2.22) presents the aggregate demand for the two outputs in terms of the exogenous model parameters, tax rates and endogenous producer prices of the two outputs and inputs respectively.

2.4 General Equilibrium with Exogenous Wage Rate

In the above we derived the input demand and output supply schedules for the profit maximising competitive firms and utility maximising consumers. We now proceed to solve for the general equilibrium of the model by imposing a set of simultaneous market clearing conditions for output and capital goods markets. This allows us to solve for the corresponding equilibrium prices of two outputs and capital. At this stage we do not specify the mechanism of wage determination, but assume that the wage rate is determined outside the model. This assumption will be relaxed later in section 2.5.

2.4.1 Commodity Market

For the two outputs, the market clearing amounts to

$$C = Y_c$$
$$D = Y_d \qquad (2.24)$$

where the left hand side refers to the aggregate consumer demand defined in (2.22) and the right hand side to the total sectoral output supply defined in (2.3). Substituting (2.3) for supplies and (2.22) for demands in (2.24) yields

$$\Lambda q_c^{(\alpha+\beta)/\Delta} q_{Lc}^{-\alpha/\Delta} q_k^{-\beta/\Delta}\left[1-\delta^{\sigma}(1+t_c)^{-\sigma}(1+s_c)^{\alpha/\Delta} q_c^{-(\Delta\sigma+\alpha+\beta)/\Delta} I_1 I_2\right]=0 \qquad (2.25)$$

and

$$\Lambda q_d^{(\alpha+\beta)/\Delta} q_{Ld}^{-\alpha/\Delta} q_k^{-\beta/\Delta}\left[1-(1-\delta)^{\sigma}(1+t_d)^{-\sigma}(1+s_d)^{\alpha/\Delta} q_d^{-(\Delta\sigma+\alpha+\beta)/\Delta} I_1 I_2\right]=0 \qquad (2.26)$$

which are the excess demand functions for the clean and polluting output, respectively. With all prices positive, (2.25) and (2.26) imply

$$1-\delta^{\sigma}(1+t_c)^{-\sigma}(1+s_c)^{\alpha/\Delta} q_c^{-(\Delta\sigma+\alpha+\beta)/\Delta} I_1 I_2=0$$
$$1-(1-\delta)^{\sigma}(1+t_d)^{-\sigma}(1+s_d)^{\alpha/\Delta} q_d^{-(\Delta\sigma+\alpha+\beta)/\Delta} I_1 I_2=0 \qquad (2.27)$$

which forms a system of two equations in two variables q_c and q_d. Equating the left hand side of the two equations and eliminating yields

$$\Delta_d \equiv \frac{q_d}{q_c}=\left[\left(\frac{1-\delta}{\delta}\frac{1+t_c}{1+t_d}\right)^{\sigma}\left(\frac{1+s_d}{1+s_c}\right)^{\alpha/\Delta}\right]^{\Delta/(\Delta\sigma+\alpha+\beta)} \qquad (2.28)$$

which can be shown to satisfy both of the equations (see Appendix 3). Thus the two equations in (2.27) are dependent and we can only solve for the relative price of the two outputs Δ_d in terms of the exogenous parameters and tax rates.[12]

2.4.2 Capital Goods Market

For market clearing in capital goods markets we require that the sum of the sectoral demands for capital equals total supply of capital in the economy. Thus, the market clearing condition can be written as

$$K_c+K_d=K_0 \qquad (2.29)$$

[12] The interdependency of the two excess demand equations is consequent on the well known Walras law. As we have derived the equation under the assumption of binding budget constraints, satisfaction of one of the equations immediately implies satisfaction of the other.

where K_i, for i= c,d refers to the sectoral demand of capital input defined in (2.2) and K_0 is the exogenous total supply of capital.[13] Substituting (2.2) for sectoral demands yields

$$\Omega_k q_k^{-(1-\alpha)/\Delta} w^{-\alpha/\Delta}\left[(1+s_c)^{-\alpha/\Delta} q_c^{1/\Delta} + (1+s_d)^{-\alpha/\Delta} q_d^{1/\Delta}\right] - K_0 = 0 \tag{2.30}$$

which is the excess demand function for capital. Solving in terms of the producer price of capital gives

$$q_k = \left(\Omega_k K_0^{-1}\right)^{\Delta/(1-\alpha)} w^{-\alpha/(1-\alpha)}\left[(1+s_c)^{-\alpha/\Delta} q_c^{1/\Delta} + (1+s_d)^{-\alpha/\Delta} q_d^{1/\Delta}\right]^{\Delta/(1-\alpha)} \tag{2.31}$$

Dividing through by q_c yields

$$\Delta_k \equiv \tfrac{q_k}{q_c} = \left(\Omega_k K_0^{-1}\right)^{\Delta/(1-\alpha)} \Delta_w^{-\alpha/(1-\alpha)}\left[(1+s_c)^{-\alpha/\Delta} + (1+s_d)^{-\alpha/\Delta} \Delta_d^{1/\Delta}\right]^{\Delta/(1-\alpha)} \tag{2.32}$$

where Δ_k is the producer price of capital expressed in terms of the non-polluting good and $\Delta_w \equiv w/q_c$ is the net wage denominated in terms of the non-polluting output. In (2.28) and (2.32) we have implicitly chosen the non-polluting output as a numeraire. This is equivalent to normalising q_c to unity. In what follows, we set $q_c \equiv 1$ and interpret all other prices as relative to the non-polluting output. Since all equations are homogenous of degree zero in prices, any other price could be chosen without loss of generality.[14] Thus, we can rewrite (2.28) and (2.32) as

$$q_d = \left[\left(\tfrac{1-\delta}{\delta}\tfrac{1+t_c}{1+t_d}\right)^{\sigma}\left(\tfrac{1+s_d}{1+s_c}\right)^{\alpha/\Delta}\right]^{\Delta/(\Delta\sigma+\alpha+\beta)} \tag{2.28'}$$

and

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[13] Note that while the total supply of capital is fixed, we allow for full mobility of capital between sectors.

[14] Setting consumer price index p equal to unity would facilitate the interpretation of relative prices as "real prices". However, choosing non-polluting output as numeraire is analytically more convenient.

$$q_k = \left(\Omega_k K_0^{-1}\right)^{\Delta/(1-\alpha)} w^{-\alpha/(1-\alpha)} \left[(1+s_c)^{-\alpha/\Delta} + (1+s_d)^{-\alpha/\Delta} q_d^{1/\Delta}\right]^{\Delta/(1-\alpha)} \qquad (2.32')$$

2.4.3 Effects of Wage Rate Changes

Equations (2.28) and (2.32) above define the equilibrium relative prices for outputs and capital input under the assumption of market clearing and exogenously determined wage rate. We now examine the effects of wage rate changes on the equilibrium prices and the level of employment. The results will be utilised in the next section where the wage determination will become endogenous.

To start with we note that equation (2.28') immediately implies

$$dq_d/dw = 0 \qquad (2.33)$$

In other words, the equilibrium relative price of the two outputs is independent of the wage rate. This is a natural implication of symmetric technology and homogenous preferences. Increase in the price of labour affects the production costs of the two outputs similarly. Also, since all consumers have identical preferences, changes in the income distribution do not affect the pattern of demand.

Next, utilising result (2.33) we differentiate (2.32') to get

$$dq_k/dw = -\tfrac{\alpha}{1-\alpha}\left(\Omega_k K_0^{-1}\right)^{\Delta/(1-\alpha)} w^{-1/(1-\alpha)} \left[(1+s_c)^{-\alpha/\Delta} + (1+s_d)^{-\alpha/\Delta} q_d^{1/\Delta}\right]^{\Delta/(1-\alpha)} \qquad (2.34)$$

Using (2.32') and multiplying both sides by q_L/q_K, we get the corresponding elasticity

$$\frac{dq_k}{dw}\frac{w}{q_k} = -\frac{\alpha}{1-\alpha} < 0 \qquad (2.35)$$

which states that the equilibrium price of capital is negatively related to the wage rate. Increased labour cost tends to reduce employment and consequently leads to lower return on capital. Thus, the two inputs are gross complements in production (see e.g. Chambers, 1988). The magnitude of the elasticity depends positively on the share of labour in the value added, α.

Next, we derive a more convenient expression of consumer price index defined in (2.16). Using the definition (2.6) to rewrite (2.16) in terms of producer rather than consumer prices and setting the producer price of non-polluting output to unity yields

$$p = \left[\delta^{\sigma}(1+t_c)^{1-\sigma} + (1-\delta)^{\sigma}(1+t_d)^{1-\sigma} q_d{}^{1-\sigma}\right]^{1/(1-\sigma)} \qquad (2.36)$$

which is the CPI denominated in terms of the non-polluting good. Equipped with the result (2.33), we see immediately from (2.36) that

$$dp/dw = 0 \qquad (2.37)$$

in other words, the consumer price index is independent of the wage rate. As the relative price of the two outputs is unaffected by a change in the wage rate, so is the consumer price index.[15]

Finally, to derive the effect on employment of an increase in the wage rate, we first recall the input demand equation (2.2) to write down sectoral labour demands in terms of relative prices. With symmetric technology, the labour demand for the non-polluting sector amounts to

$$L_c = \Omega_L q_k^{-\beta/\Delta} q_{Lc}^{-(1-\beta)/\Delta} \qquad (2.38)$$

[15] It should be noted that the result (2.37) is dependent on the choice of numeraire and does not reflect general independence between wages and consumer prices.

Similarly, for the polluting sector we get

$$L_d = \Omega_L q_d^{1/\Delta} q_k^{-\beta/\Delta} q_{Ld}^{-(1-\beta)/\Delta} \tag{2.39}$$

The aggregate labour demand is equal to the sum of sectoral demands and can thus be written as

$$L = L_c + L_d = \Omega_L q_k^{-\beta/\Delta} w^{-(1-\beta)/\Delta}\left[(1+s_c)^{-(1-\beta)/\Delta} + (1+s_d)^{-(1-\beta)/\Delta} q_d^{1/\Delta}\right] \tag{2.40}$$

To find the effect of exogenous changes in the labour cost we differentiate (2.40) with respect to the wage rate to get

$$\tfrac{dL}{dw} = \Omega_L\left[(1+s_c)^{-(1-\beta)/\Delta} + (1+s_d)^{-(1-\beta)/\Delta} q_d^{1/\Delta}\right] q_k^{-\beta/\Delta} w^{-(1-\beta)/\Delta}\left[-\tfrac{1-\beta}{\Delta} q_L^{-1} - \tfrac{\beta}{\Delta} q_k^{-1} \tfrac{dq_k}{dq_L}\right] \tag{2.41}$$

where we have utilised result (2.33) on the constancy of the relative price of the outputs. Using (2.40) and multiplying both sides by *w/L*, we get the corresponding elasticity

$$\tfrac{dL}{dw}\tfrac{w}{L} = \left[-\tfrac{1-\beta}{\Delta} - \tfrac{\beta}{\Delta}\left(\tfrac{dq_k}{dw} w q_k^{-1}\right)\right] \tag{2.42}$$

The elasticity within the brackets in (2.42) is nothing but the elasticity of capital price with respect to the labour cost derived in (2.35). Equation (2.42) decomposes the effect of a wage hike into two components. First term inside the square brackets is the elasticity of labour demand for fixed return on capital. The second term allows for a decline in the return on capital reducing the elasticity in absolute value. Intuitively, part of the burden of a wage hike is borne by capital and the employment of labour drops less.

Substituting (2.35) for the elasticity inside the brackets and using the definition $\Delta \equiv 1-\alpha-\beta$, we get

$$-\frac{dL}{dw}\frac{w}{L}=\frac{1}{1-\alpha} \qquad (2.43)$$

which defines the "general equilibrium wage elasticity of aggregate labour demand" in the model.[16] We note that the right hand side of (2.43) only depends on the exogenous technology parameter, α. Thus, the labour demand elasticity is constant, confirming the well known result of models with Cobb-Douglas technology (see e.g. Holmlund et al, 1989). Furthermore, with Cobb-Douglas technology α reflects the share of labour in the value added of profit maximising firms (e.g. Varian, 1984). Intuitively, the larger the share of labour in value added the more the adjustment to a wage hike is reflected in lower employment as capital and profits are unable to accommodate the increased costs.

The form of the elasticity in (2.43) corresponds to that of a "restricted technology" labour demand elasticity of a competitive firm (Varian, 1984), which is derived conditional on a fixed capital input. The similarity between the two expressions is understandable: In the present model, the output price is unaffected by a change in the labour cost as implied by (2.33) and the equilibrium price of capital is derived from a market clearing condition with fixed total supply.[17]

2.5 Wage Formation and Labour Market Equilibrium

In the above we derived the general equilibrium under the assumption of market clearing for outputs and capital input. The determination of the wage rate was assumed exogenous. In this section we endogenize the wage determination by introducing a wage setting trade union into the model.

To determine labour market equilibrium, we assume a monopoly union structure (see e.g. Booth, 1995). A centralised trade union is supposed to choose the wage

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[16] It should be noted that we have derived the labour demand elasticity with respect to the product wage denominated in the non-polluting output, which has implicitly been chosen as numeraire.

[17] It should be noted that although (2.43) implies an elasticity greater than one, the sectoral constant output elasticities implied by the model can be shown to be less than one thus being in line with the estimates reported in the econometric literature.

rate so as to maximise its objective, taking account of the demand response from the firms. The competitive firms will then unilaterally decide on employment. The monopoly union structure is widely used in modelling corporative labour markets. The key results are qualitatively similar, but the exposition simpler than in the somewhat more realistic bargaining models (see e.g. Holmlund et al, 1989). Unionised labour markets typically lead to involuntary unemployment as wages are set above the market clearing level.[18]

2.5.1 Union Objective and Scope

To introduce a trade union into the model we assume a utilitarian objective function widely used in the literature (for a survey on union objectives see e.g. Booth, 1995). As some of the union members will be unemployed this amounts to maximising the weighted sum of utilities employed and unemployed members. Following Driffill & van der Ploeg (1993), we further assume that individual utilities are linear on the after tax real wage and real benefit level, respectively.[19] Then, the objective of the union can be written

$$V = Lp_L/p + (M - L)b_n/p \tag{2.44}$$

where M is the number of union members, L is the number of employed members, p_L is the net wage after tax or consumer price of labour, p is the consumer price index and b_n is the unemployment benefit.

A major characteristic in the theory of labour unions is the degree of centralisation in the wage formation. The key result is that both highly decentralised and highly centralised systems result in greater wage restraint and higher employment than

[18] Alternative ways to model unemployment including efficiency wages and job search are nicely compared in Pissarides (1998).

[19] Note that in our model income of consumers includes return on capital and profits. We assume, however, that union is only interested in incomes related to labour markets, i.e. wages and unemployment benefits.

intermediate cases (Calmfors and Driffill, 1988). In the decentralised systems wages are moderated by market forces. In the centralised systems wage restraint is based on the ability to internalise the negative externalities of wage hikes in the rest of the economy e.g. increased consumer prices. A high degree of centralisation has been thought to characterise the labour markets particularly in the Nordic countries.[20]

In what follows, we assume a centralised union acting at the top level of the economy. To implement the centralisation, we assume that the union takes account of the effect of its wage policies on the general price level, which is the approach suggested by Hoel (1991) and Driffill & van der Ploeg (1993).[21] Taxes and other government policies are taken as being predetermined by the union. We also assume that the union does not take account of the link between taxes paid and benefits received by the members.[22]

2.5.2 Derivation of the Wage Equation

With the premises discussed above, we now apply (2.44) to the model framework. Writing (2.8) for consumer price of labour and using the definition of unemployment benefits we get

$$V = L(1 - t_L)w/p + (M - L)b \qquad (2.45)$$

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20 For a survey of the theoretical foundation and the empirical observations of union centralisation see Calmfors (1993).

21 There are different approaches to allow for varying degrees of centralisation in the union models. For discussion and results see e.g. Calmfors and Driffill (1988), Hoel (1991) and Driffill & van der Ploeg (1993).

22 An alternative approach where union to some extent perceives the tax-benefit link has been suggested by Summers et al (1993) and Alesina & Perotti (1997). Unlike their model, ours accommodates alternative tax instruments for financing the benefits so linking benefits to one particular tax rate is not necessarily relevant.

where L is the aggregate labour demand defined in (2.40), w is the net wage and b is the unemployment benefit in real terms. Rearranging (2.45) gives

$$V = L[(1 - t_L)w/p - b] + Mb \qquad (2.45')$$

Now assume that the trade union aims to maximise its objective by setting a preferred wage rate in terms of the non-polluting output . Then differentiating (2.45') with respect to the net wage yields the first order condition for union's optimum[23]

$$(dL/dw)[(1 - t_L)wp^{-1} - b] + L(1 - t_L)p^{-1}[1 - wp^{-1}(dp/dw)] = 0 \qquad (2.46)$$

multiplying trough by wL^{-1} gives

$$-\varepsilon[(1 - t_L)wp^{-1} - b] + (1 - t_L)wp^{-1}[1 - \vartheta] = 0 \qquad (2.46')$$

where

$$\varepsilon \equiv -\frac{dL}{dw}\frac{w}{L}$$

is the elasticity of labour demand with respect to net wage. And

$$\vartheta \equiv \frac{dp}{dw}\frac{w}{p}$$

is the elasticity of CPI with respect to net wage. Solving (2.46') for the wage rate gives

$$w = bp(1 - t_L)^{-1}\left(1 - \tfrac{1-\vartheta}{\varepsilon}\right)^{-1} \qquad (2.47)$$

---

23 Note that the second term in (2.45') is exogenous from union's point of view and can thus be ignored in optimisation. Second order necessary conditions for the optimum are presented in appendix 4.

which constitutes the optimal wage rate of a "centralised" trade union (see Driffill & van der Ploeg, 1993). For the wage rate to be positive we must have $\varepsilon + \vartheta > 1$, which is a modification of the well known prerequisite for a monopoly union model of elastic labour demand.

The equation (2.47) decomposes the union wage into "competitive wage" and union mark-up. The competitive net wage $w{*}= bp(1-t_L)^{-1}$ would prevail if the consumers would freely allocate their time endowment between employment and unemployment. The marginal real product of labour net of taxes would be equalised with the real unemployment benefit guaranteed by the government.[24] The competitive wage is proportional to the real unemployment benefit and consumer price index and depends positively on the rate of labour income tax.

The second bracketed term in the right hand side of (2.47) represents a union mark-up over the competitive wage. We see that with $\varepsilon > 0$ and $\vartheta < 1$ the term exceeds unity and there is a positive mark-up. In other words, as long as labour demand responds negatively to increased labour costs, and wage hikes are less than perfectly transferred to consumer prices, the union sets wages above the competitive level. The size of the mark-up is inversely related to the wage elasticity of labour demand and wage elasticity of consumer price index. Intuitively, the more responsive employment and consumer prices are, the more moderate wage policies are expected to be as it becomes more profitable for the union to trade off wages for employment.

Next, to implement wage equation (2.47) in terms of the model parameters we substitute the formulas derived in section 3.3 for the elasticities involved. Recalling the result (2.43) defining labour demand elasticity with respect to the net wage, we have

$$\varepsilon = \frac{1}{1-\alpha} \qquad (2.48)$$

---

24 We abstract from the potentially positive valuation of leisure here. Also note that "competitive wage" would not imply full employment.

Further, in (2.37) we noted that consumer price index is independent of the wage rate. This implicates directly

$$\vartheta = 0 \tag{2.49}$$

By (2.48) and (2.49) we have indeed $\varepsilon > 0$, $\vartheta < 1$ and $\varepsilon + \vartheta > 1$. Consequently, the union sets a non-negative wage rate that has a mark-up over the competitive wage. Substituting (2.48) and (2.49) for the corresponding elasticities in (2.47) gives

$$w = \frac{bp}{\alpha(1-t_L)} \tag{2.50}$$

Using definition (2.9) we can rewrite (2.50) in terms of the producer price of labour

$$q_{Li} = \frac{(1+s_i)bp}{\alpha(1-t_L)} \tag{2.50'}$$

where s_i refers to the sector specific payroll tax rate on labour.

Equation (2.50) shows that the union mark-up coefficient in the model equals $1/\alpha > 1$. Thus there is a constant positive mark up which is inversely related to the share of labour in the value added. As the share of labour approaches unity, the mark up disappears. Intuitively, the union tries to extract some of the profits and capital compensation. This is the easier the higher the share of profits and capital compensation in the value added of the profit maximising firms.[25]

In section 2.4 we imposed the market clearing conditions for commodity and capital markets to determine the respective equilibrium prices. Adding the wage equation (2.50) rounds off the model to a general equilibrium model with the non-clearing labour market and endogenous wage determination by a monopoly union. The economy wide level of employment is thus determined by the aggregate labour

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[25] It can be shown that the size mark-up is independent of the choice of numeraire. Thus, the model preserves neutrality of money.

demand equation (2.40). In the next section we proceed to derive some results concerning the effects of tax policies within such a framework.

3. Comparative Statics of Tax Changes

Having derived the general equilibrium we can now proceed to present some comparative statics results for changes in the tax parameters. In particular, we want to find out how changes in certain tax rates affect the equilibrium level of employment and environmental quality, the latter being reflected by changes in the equilibrium level of the polluting output. With reference to the double dividend problem, we first consider exogenous changes in the labour income tax and the consumption tax on the polluting output. The effects of a sector specific payroll tax are derived in section 3.2.

3.1 Effects of Labour Income and Environmental Taxes

In this section we consider exogenous changes in the labour income tax and the consumption tax on the polluting output. It is assumed that the benchmark is characterised by a uniform payroll tax on labour.[26]

3.1.1 Effects on Employment

We first take a look at the effects of changes in the tax rates on the equilibrium level of employment. For that purpose we recall the sectoral labour demand equations (2.38) and (2.39).[27] With payroll tax rates equal across sectors we get

$$L_c = \Omega_L q_k^{-\beta/\Delta} q_L^{-(1-\beta)/\Delta}$$

$$L_d = \Omega_L q_d^{1/\Delta} q_k^{-\beta/\Delta} q_L^{-(1-\beta)/\Delta}$$

---

[26] In section 5 we will show that changes in the uniform payroll tax have exactly the same effects on real variables as changes in the labour income tax.

[27] Since employment in the model is determined by labour demand (section 2.5) we can refer to employment and labour demand as interchangeable in what follows.

where $q_L = (1+s)w$ and s is the uniform rate of payroll tax on labour. Aggregate employment is then given by (2.40)

$$L = L_c + L_d = \Omega_L q_k^{-\beta/\Delta} q_L^{-(1-\beta)/\Delta}\left(1 + q_d^{1/\Delta}\right)$$

Substituting equilibrium price of capital given by (2.32') for q_k then yields

$$L = \Omega_L\left[\Omega_k^{-\beta} K_0^{\beta}\left(1 + q_d^{1/\Delta}\right)^{\Delta} q_L^{-1}\right]^{1/(1-\alpha)} \quad (3.1)$$

Equation (3.1) determines aggregate employment in terms of technology parameters, exogenous total supply of capital, the relative price of the two sectoral outputs and producer price of labour denominated in the non-polluting output.

To find the effect of a change in the labour income tax on equilibrium employment we differentiate (3.1) to get

$$\frac{dL}{d(1-t_L)} = L_{ql}\left(\frac{dq_L}{d(1-t_L)}\right) + L_{qd}\left(\frac{dq_d}{d(1-t_L)}\right) \quad (3.2)$$

Equation (3.2) decomposes the effect of labour income tax into two components. The first term on the right hand side reflects the effect through producer price of labour. The second term on the right hand side reflects the additional effect due to a possible change in the relative price of outputs. To determine the sign of the employment effect we need to find out the signs of the four derivatives on the right hand side of (3.2).

We first derive the signs of the two partial derivatives. Differentiating (3.1) with respect to the producer price of labour yields

$$L_{ql} \equiv \partial L/\partial q_L = -(1-\alpha)^{-1}\Omega_L\left[\Omega_K^{-\beta} K_0^{\beta}\left(1 + q_d^{1/\Delta}\right)^{\Delta} q_L^{\alpha-2}\right]^{1/(1-\alpha)} < 0 \quad (3.3)$$

According to (3.3), for given output prices an increase in the labour cost reduces aggregate employment, which is a straightforward consequence of profit maximising behaviour by the firms. Similarly, differentiating (3.1) with respect to the producer price of polluting output holding producer price of labour fixed, yields

$$L_{qd} \equiv \partial L/\partial q_d = (1-\alpha)^{-1}\Omega_L q_d^{(\alpha+\beta)/\Delta}\left[\Omega_K^{-\beta}K_0^{\beta}\left(1+q_d^{1/\Delta}\right)^{-\beta}q_L^{-1}\right]^{1/(1-\alpha)} > 0 \qquad (3.4)$$

in other words, for given producer price of labour, an increase in the producer price of polluting output increases employment. Intuitively, as we have defined the wage rate in terms of the non-polluting output, an increase in the relative price of the polluting output makes the product wage in the polluting sector lower and boosts employment there. At the same time, the product wage in the non-polluting sector stays unchanged and the total effect on employment is positive.

Next, we need to find the signs of the two derivatives within the brackets on the right hand side of (3.2). For that purpose, we first rewrite the equation (2.28') with uniform payroll tax to get

$$q_d = \left[\frac{1-\delta}{\delta}\frac{1+t_c}{1+t_d}\right]^{\Delta\sigma/(\Delta\sigma+\alpha+\beta)}$$

which defines the equilibrium relative price of the outputs in terms of model parameters and commodity tax rates. Then it is immediately obvious that

$$\frac{dq_d}{d(1-t_L)} = 0 \qquad (3.5)$$

in other words, changes in the labour income tax has no effect on the relative price of the polluting output. Result (3.5) follows from the assumption of symmetric technology across sectors. Labour income tax treats both sectors equally and does not disturb allocation of resources between sectors.

Finally, to find the effect of labour income tax on the producer price of labour we recall the wage equation (2.50'). Substituting expression (2.36) for consumer price index in (2.50') gives

$$q_L = \alpha^{-1} b(1+s)(1-t_L)^{-1}\left[\delta^{\sigma}(1+t_c)^{1-\sigma} + (1-\delta)^{\sigma}(1+t_d)^{1-\sigma} q_d{}^{1-\sigma}\right]^{1/(1-\sigma)} \qquad (2.50'')$$

which defines the equilibrium price of labour in terms of model parameters, tax rates and producer price of the polluting output. Differentiating (2.50") with respect to the labour income tax yields

$$\frac{dq_L}{d(1-t_L)} = \frac{\partial q_L}{\partial(1-t_L)} + \frac{\partial q_L}{\partial q_d}\frac{dq_d}{d(1-t_L)} \qquad (3.6)$$

Equation (3.6) decomposes the effect of labour income tax into two components. The first term on the right hand side gives the effect on wages with fixed output prices. The second term on the right hand side reflects the effect of changes in the price level on wages. According to (3.5) the price level will not be affected and the latter term in (3.6) will be zero.

Formally, substituting (3.5) into (3.6) and differentiating (2.50") partially with respect to the labour tax rate gives

$$\frac{dq_L}{d(1-t_L)} = \frac{\partial q_L}{\partial(1-t_L)} = -\frac{(1+s)b}{\alpha(1-t_L)^2}p < 0 \qquad (3.7)$$

in other words, a decrease in the labour income tax serves to lower net wages and consequently the producer price of labour. As we will note in section 4, this result is sensitive to the tax treatment of unemployment benefits. A similar result has been derived in the single input model with wage bargaining by Koskela & Schöb (1998).

Applying the signs derived in (3.3), (3.4), (3.5) and (3.7) into equation (3.2) shows that the first term on the right hand side is positive while the second is zero. The effect of labour income tax on employment arrives solely by wage formation and is negative. We conclude that an increase (decrease) in the tax rate on labour income, will reduce (increase) employment in the model.

Next, turning to the environmental tax, we differentiate (3.1) with respect to the tax rate on the polluting output to get

$$\frac{dL}{d(1+t_d)} = L_{ql}\left(\frac{dq_L}{d(1+t_d)}\right) + L_{qd}\left(\frac{dq_d}{d(1+t_d)}\right) \tag{3.8}$$

Equation (3.8) decomposes the effect of environmental tax into two components. The first term on the right hand side reflects the effect by wage formation and producer price of labour. The second term on the right hand side reflects the effect due to a change in the relative price of the outputs for given producer price of labour. The signs of the two partial derivatives of labour demand are as derived in (3.3) and (3.4).

To find the signs of the derivatives within brackets on the right hand side of (3.8) we differentiate the corresponding equilibrium price equations with respect to the tax rate on the polluting output. First, differentiating the output price equation (2.28') with respect to the environmental tax gives

$$\frac{dq_d}{d(1+t_d)} = -\frac{\Delta\sigma}{\alpha+\beta+\Delta\sigma}\left[\frac{(1-\delta)(1+t_c)}{\delta(1+t_d)}\right]^{\left(\frac{\Delta\sigma}{\alpha+\beta+\Delta\sigma}\right)-1}\delta^{-1}(1-\delta)(1+t_c)(1+t_d)^{-2} < 0 \tag{3.9}$$

in other words, an increase in the environmental tax decreases the relative producer price of the polluting output. Intuitively, part of the tax burden of the consumption tax is borne by the producers.

Next, differentiating the wage equation (2.50") with respect to the environmental tax gives

$$\frac{dq_L}{d(1+t_d)} = \frac{\partial q_L}{\partial(1+t_d)} + \frac{\partial q_L}{\partial q_d}\frac{dq_d}{d(1+t_d)} \tag{3.10}$$

When interpreting (3.10) we must keep in mind that output taxes enter the wage equation (2.50') through consumer price index, only. According to (3.10) the effect of the environmental tax on CPI and thus on wages can be decomposed into two separate effects. The first term on the right hand side of (3.10) is a direct effect with fixed relative price of the two outputs. The second term on the right hand side of (3.10) reflects an indirect effect due to the induced change in the relative price of the two outputs.

To determine the sign of (3.10) and thus the effect of environmental tax on wages, we need to find the signs of the two components on the right hand side. First, we partially differentiate the wage equation (2.50") with respect to the environmental tax to get

$$\frac{\partial q_L}{\partial(1+t_d)} = \frac{b(1+s)}{\alpha(1-t_L)}(1-\delta)^{\sigma}(1+t_d)^{-\sigma}q_d^{\;1-\sigma}\left[\delta^{\sigma}(1+t_c)^{1-\sigma}+(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d^{\;1-\sigma}\right]^{\sigma/(1-\sigma)}>0 \tag{3.11}$$

in other words, for fixed producer prices, an increase in the environmental tax will increase CPI and thus wages. Next, partially differentiating the wage equation (2.50") with respect to producer price of the polluting output gives

$$\frac{\partial q_L}{\partial q_d} = \frac{(1-\beta)(1+s)b}{\alpha(1-t_L)}\left[\delta^{\sigma}(1+t_c)^{1-\sigma}+(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d^{\;1-\sigma}\right]^{\sigma/(1-\sigma)}(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d^{\;-\sigma}>0 \tag{3.12}$$

According to (3.12) a ceteris paribus increase in the producer price of polluting output increases CPI and thus wages. Thus by (3.9), (3.11) and (3.12) the sign of (3.10) is a priori ambiguous. Intuitively, the environmental tax has two opposite effects on wages: on the one hand wages tend to increase as the increasing tax rate puts an upward pressure on consumer prices. On the other hand, this pressure is mitigated by a drop in the producer price of the polluting output. We cannot tell, without further investigation, whether wages will increase or decrease due to higher environmental tax. Consequently, the sign of the employment effect remains unknown.

However, through further substitution of the equilibrium output price equation we can show that in (3.10) the positive direct effect always dominates (see Appendix 5). Thus (3.10) is positive and an increase in the environmental tax leads to higher wages. Applying the signs of (3.3), (3.4), (3.9) and (A5.5) to the expression (3.8) we note that both terms on the right hand side are negative. The environmental tax increases wages which has a negative effect on employment. This effect is fortified by a drop in the relative price of the polluting output which tends to reduce employment in the polluting sector. We conclude that an increase (decrease) in the tax rate on the polluting good, will reduce (increase) employment in the model.

3.1.2 Effects on the Environment

Turning to the environmental effects of tax policy changes, we invoke the output supply function (2.3) for the polluting sector. With symmetric technology and uniform payroll tax on labour, we have

$$Y_d = \Lambda\left[q_d^{\alpha+\beta} q_k^{-\beta} q_L^{-\alpha}\right]^{1/\Delta} \tag{2.3'}$$

Substituting the equilibrium price of capital given by (2.32') yields

$$Y_d = \Lambda\left[\Omega_k^{-\beta} K_0^{\beta}\left(1+q_d^{1/\Delta}\right)^{-\beta} q_L^{-\alpha}\right]^{1/(1-\alpha)} q_d^{(\alpha+\beta)/\Delta} \tag{3.13}$$

Differentiating (3.13) with respect to the labour tax gives

$$\frac{dY_d}{d(1-t_L)} = Y_{ql}\left(\frac{dq_L}{d(1-t_L)}\right) + Y_{qd}\left(\frac{dq_d}{d(1-t_L)}\right) \tag{3.14}$$

According to (3.14) the effect of the labour income tax on the level of polluting output can be decomposed into two effects. The first term on the right hand side of (3.14) is an effect through the wage rate. The second term reflects an additional effect through a possible change in the relative price of the two outputs. The sign of the environmental effect is determined by the signs of the four derivatives on the right hand side of (3.14).

The signs of the derivatives within brackets on the right hand side of (3.14) have already been derived above in (3.5) and (3.7). To derive the signs of the partial derivatives of polluting output, we first partially differentiate (3.13) with respect to producer price of labour to get

$$Y_{ql} \equiv \partial Y_d / \partial q_L = -\frac{\alpha}{1-\alpha}\Lambda\left[\Omega_k^{-\beta} K_0^{\beta}\left(1+q_d^{1/\Delta}\right)^{-\beta} q_L^{-1}\right]^{1/(1-\alpha)} q_d^{(\alpha+\beta)/\Delta} < 0 \tag{3.15}$$

Equation (3.15) states that a ceteris paribus increase in the producer price of labour decreases the level of polluting output and thus improves environmental quality. Intuitively, an isolated increase in the cost of input tends to reduce output by profit maximising producers.

Next, we partially differentiate (3.13) with respect to producer price of polluting output to get

$$
\begin{aligned}
Y_{qd} &\equiv \partial Y_d / \partial q_d \\
&= \Lambda\left[\Omega_k^{-\beta} K_0^{\beta} q_L^{-\alpha}\right]^{\frac{1}{1-\alpha}} \left[\frac{\alpha+\beta}{\Delta} q_d^{\frac{\alpha+\beta-\Delta}{\Delta}} \left(1+q_d^{1/\Delta}\right)^{\frac{\beta}{\alpha-1}} - \frac{\beta}{(1-\alpha)\Delta} q_d^{\frac{2(\alpha+\beta)}{\Delta}} \left(1+q_d^{1/\Delta}\right)^{\frac{1-\alpha+\beta}{\alpha-1}} \right] \\
&= \Lambda \frac{\alpha+\beta}{\Delta}\left[\Omega_k^{-\beta} K_0^{\beta} q_L^{-\alpha}\right]^{\frac{1}{1-\alpha}} q_d^{\frac{\alpha+\beta-\Delta}{\Delta}} \left(1+q_d^{1/\Delta}\right)^{\frac{\beta}{\alpha-1}} \left[1 - \frac{\beta}{(1-\alpha)(\alpha+\beta)} q_d^{1/\Delta} \left(1+q_d^{1/\Delta}\right)^{-1} \right] \\
&= \Lambda \frac{\alpha+\beta}{\Delta}\left[\Omega_k^{-\beta} K_0^{\beta} q_L^{-\alpha}\right]^{\frac{1}{1-\alpha}} q_d^{\frac{\alpha+\beta-\Delta}{\Delta}} \left(1+q_d^{1/\Delta}\right)^{\frac{\beta}{\alpha-1}} \left[1 - \frac{\beta}{\beta+\Delta\alpha} q_d^{1/\Delta} \left(1+q_d^{1/\Delta}\right)^{-1} \right] \\
&= \Lambda \frac{\alpha+\beta}{\Delta}\left[\Omega_k^{-\beta} K_0^{\beta} q_L^{-\alpha}\right]^{\frac{1}{1-\alpha}} q_d^{\frac{\alpha+\beta-\Delta}{\Delta}} \left(1+q_d^{1/\Delta}\right)^{\frac{\beta}{\alpha-1}} \left[\left(1 + \frac{\Delta\alpha}{\beta+\Delta\alpha} q_d^{1/\Delta}\right) \left(1+q_d^{1/\Delta}\right)^{-1} \right] > 0 \qquad (3.16)
\end{aligned}
$$

According to (3.16) a ceteris paribus increase in the producer price of the polluting output increases the equilibrium level of the polluting output with a given price of labour and thus worsens environmental quality. Intuitively, a favourable price shock tends to increase the supply of output by profit maximising producers.

Thus, by (3.5), (3.7), (3.15) and (3.16) the right hand side of (3.14) is strictly positive implicating an increase in the level of polluting output after a decrease in the labour income tax. The drop in the labour income tax reduces wages and thus boosts polluting output as the output price is not affected. Given the strictly monotone relationship between the level of the polluting good consumed and environmental damage, we conclude that an increase (decrease) in the tax rate on labour income, will improve (worsen) the environmental quality in the model.

Finally, to find the effects of the environmental tax on pollution we differentiate (3.13) with respect to the tax rate on polluting output to get

$$
\frac{dY_d}{d(1+t_d)} = Y_{ql}\left(\frac{dq_L}{d(1+t_d)}\right) + Y_{qd}\left(\frac{dq_d}{d(1+t_d)}\right) < 0 \qquad (3.17)
$$

the sign of which is given by (3.9), (A5.5), (3.15) and (3.16). An increase in the environmental tax decreases the relative producer price of polluting output which tends reduce output in that sector. This effect is fortified by the increased producer price of labour that follows from the higher wage bid by the union facing increased consumer prices. We conclude that an increase (decrease) in the tax rate on the polluting good, will improve (worsen) environmental quality in the model.

In summary, the comparative statics show that both labour income tax and the environmental tax have a negative effect on employment and a positive effect on the environmental quality. Therefore, we cannot tell, a priori, what would be the effect on employment and the environment of a green tax reform that increases environmental tax and decreases labour income tax.

3.2 Effects of the Sector Specific Payroll Tax

In section 3.1 we derived the effects on employment and the environment of increases in the tax rates on labour income and polluting output, respectively. We assumed throughout that the payroll tax on labour was collected at an equal rate in the two production sectors. In this section we consider the effects on employment and the environment of an uncompensated increase in the payroll tax on the non-polluting sector only.

Differentiated rates of payroll taxes or social security contributions as a means of increasing employment have been proposed by e.g. Dreze & Malinvaud (1994). In their analysis, however, payroll tax rates would be differentiated according to wage rates rather than production sectors. Myles (1995) has shown that differentiated payroll rates by sector may be desirable even on efficiency grounds if competition in the output market is imperfect. A recent contribution by Kolm (1998) incorporates wage bargaining in the labour markets and finds positive employment effects conditional on a wage premium between sectors.[28] In our analysis, it is environmental harmfulness rather than the degree of competition which forms the basis of payroll tax differentiation between sectors.

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[28] Holm et al (1995) provide an empirical assessment of the employment effects of non-uniform payroll tax rates. They consider rates differentiation according to wage level, capital intensity and sectoral unemployment record.

3.2.1 Effects on Employment

To derive the effect on employment of an increase in the payroll tax in the non-polluting sector, we recall the equation (2.40) defining the aggregate equilibrium level of employment

$$L = \Omega_L q_k^{-\beta/\Delta} w^{-(1-\beta)/\Delta}\left[(1+s_c)^{-(1-\beta)/\Delta} + (1+s_d)^{-(1-\beta)/\Delta} q_d^{1/\Delta}\right]$$

substituting (2.32') for the equilibrium price of capital, q_k, yields, after some manipulation

$$L = \Omega_L\left(\Omega_k K_0^{-1}\right)^{-\beta/(1-\alpha)} w^{-1/(1-\alpha)}(1+s_d)^{-1/(1-\alpha)}\left[s_{cd}^{(1-\beta)/\Delta} + q_d^{1/\Delta}\right]\left[s_{cd}^{\alpha/\Delta} + q_d^{1/\Delta}\right]^{-\beta/(1-\alpha)} \quad (3.18)$$

where

$$s_{cd} \equiv \frac{1+s_d}{1+s_c} \quad (3.19)$$

stands for the ratio of the sector specific payroll taxes. Equation (3.18) defines the equilibrium level of employment as a function of net wage, the relative price of the outputs and the sector specific payroll tax rates. Differentiating with respect to the payroll tax in the non-polluting sector then yields

$$\frac{dL}{d(1+s_c)} = L_s\left(\frac{ds_{cd}}{d(1+s_c)}\right) + L_{qd}\left(\frac{dq_d}{d(1+s_c)}\right) + L_w\left(\frac{dw}{d(1+s_c)}\right) \quad (3.20)$$

which decomposes the effect on employment of payroll tax into three components. The first term on the right hand side reflects the direct effect with the relative price of the outputs and wages unchanged. The second term reflects the effect through the relative price of the two outputs for a given wage rate. Finally, the third term gives the additional effect through the wage formation. To determine the effect of an increase in the payroll tax in the non-polluting sector, we must derive the sign of expression (3.20).

We start with the partial derivatives. Differentiating (3.18) and evaluating at the starting point with equal payroll rates across sectors, gives

$$\begin{aligned} L_s \equiv \partial L/\partial s_{cd} &= \Phi_1 \left\{ \tfrac{1-\beta}{\Delta} s_{cd}^{\frac{1-\beta}{\Delta}-1} \left[s_{cd}^{\alpha/\Delta} + q_d^{1/\Delta} \right]^{\frac{-\beta}{1-\alpha}} - \tfrac{\alpha\beta}{\Delta(1-\alpha)} s_{cd}^{\frac{\alpha}{\Delta}-1} \left[s_{cd}^{(1-\beta)/\Delta} + q_d^{1/\Delta} \right] \left[s_{cd}^{\alpha/\Delta} + q_d^{1/\Delta} \right]^{\frac{-\beta}{1-\alpha}-1} \right\} \\ &= \Phi_1 s_{cd}^{\frac{1-\beta}{\Delta}-1} \left[1 + q_d^{1/\Delta} \right]^{\frac{-\beta}{1-\alpha}} \left\{ \tfrac{1-\beta}{\Delta} - \tfrac{\alpha\beta}{\Delta(1-\alpha)} \right\} \\ &= \Phi_1 s_{cd}^{\frac{1-\beta}{\Delta}-1} \left[1 + q_d^{1/\Delta} \right]^{\frac{-\beta}{1-\alpha}} \left\{ \tfrac{1}{1-\alpha} \right\} > 0 \end{aligned} \tag{3.21}$$

where

$$\Phi_1 \equiv \Omega_L \left(\Omega_k K_0^{-1} \right)^{-\beta/(1-\alpha)} w^{-1/(1-\alpha)} (1 + s_d)^{-1/(1-\alpha)} > 0$$

and the second equality follows from setting $s_{cd} = 1$. According to (3.21), starting from a uniform payroll tax, a decrease[29] in the payroll tax rate of the non-polluting sector will improve total employment given that relative output price and wage level are fixed. Intuitively, producers' real labour cost will drop in the non-polluting sector and remain unchanged in the polluting sector. Therefore, the effect on aggregate employment is positive.

Next, we differentiate (3.18) with respect to the relative price of the two outputs to get

$$\begin{aligned} L_{qd} \equiv \partial L/\partial q_d &= \Phi_1 \left\{ \tfrac{1}{\Delta} q_d^{\frac{1}{\Delta}-1} \left[s_{cd}^{\alpha/\Delta} + q_d^{1/\Delta} \right]^{\frac{-\beta}{1-\alpha}} - \tfrac{\beta}{\Delta(1-\alpha)} q_d^{\frac{1}{\Delta}-1} \left[s_{cd}^{(1-\beta)/\Delta} + q_d^{1/\Delta} \right] \left[s_{cd}^{\alpha/\Delta} + q_d^{1/\Delta} \right]^{\frac{-\beta}{1-\alpha}-1} \right\} \\ &= \left\{ 1 - \tfrac{\beta}{1-\alpha} \right\} \Phi_1 \tfrac{1}{\Delta} q_d^{\frac{1}{\Delta}-1} \left(1 + q_d^{1/\Delta} \right)^{\frac{-\beta}{1-\alpha}} > 0 \end{aligned} \tag{3.22}$$

---

29 Note that we have defined the ratio of payroll taxes with the non-polluting sector in the denominator. Thus, an increase in the ratio implies a decrease in the payroll tax of the non-polluting sector.

where the second equality again follows from setting $s_{cd} = 1$. Equation (3.22) states that a change in the relative producer price of the outputs in favour of the polluting output has a positive influence on employment as long as the wage level is fixed. As the wage level is fixed relative to the non-polluting output, the producers' real labour cost will drop in the polluting sector and remain unchanged in the non-polluting sector. Thus, the effect on aggregate employment is positive.

Finally, we similarly derive the third partial derivative to get

$$L_w \equiv \partial L/\partial w = -\tfrac{1}{1-\alpha}\Phi_1 w^{-1}\left[s_{cd}^{(1-\beta)/\Delta} + q_d^{1/\Delta}\right]\left[s_{cd}^{\alpha/\Delta} + q_d^{1/\Delta}\right]^{\frac{-\beta}{1-\alpha}} < 0 \qquad (3.23)$$

According to (3.23), a ceteris paribus increase in the wage rate has a negative effect on employment, which is a standard result stemming from the profit maximising behaviour of the firms.

We then proceed to derive the signs of the derivatives within brackets on the right hand side of (3.20). We first note that

$$\frac{ds_{cd}}{d(1+s_c)} = -\frac{1+s_d}{(1+s_c)^2} < 0 \qquad (3.24)$$

Then, we differentiate expression (2.28') for the equilibrium price of output to get

$$\frac{dq_d}{d(1+s_c)} = \frac{dq_d}{ds_{cd}}\frac{ds_{cd}}{d(1+s_c)} < 0 \qquad (3.25)$$

where the sign follows from (3.24) and from

$$\frac{dq_d}{ds_{cd}} = \left(\frac{\alpha}{\Delta\sigma+\alpha+\beta}\right) q_d s_{cd}^{-1} > 0 \qquad (3.26)$$

Equation (3.25) simply states that an increase in the payroll tax in the non-polluting sector decreases the relative producer price of the polluting output in equilibrium.

Intuitively, the employers in the non-polluting sector shift some of the increased tax burden to the consumers through higher output prices. Therefore, the relative price of the polluting output drops.

Finally, substituting consumer price index (2.36) in the wage equation (2.50), differentiating and evaluating at the point of equal payroll rates gives

$$\frac{dw}{d(1+s_c)} = \frac{\partial w}{\partial q_d}\frac{dq_d}{d(1+s_c)} < 0 \tag{3.27}$$

where the sign follows from (3.25) and from

$$\begin{aligned}\frac{\partial w}{\partial q_d} &= \frac{b}{\alpha(1-t_L)}(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d{}^{-\sigma}\left[\delta^{\sigma}(1+t_c)^{1-\sigma}+(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d{}^{1-\sigma}\right]^{\sigma/(1-\sigma)} \\ &= w(1-\delta)^{\sigma}q_d{}^{-\sigma}[\delta^{\sigma}+(1-\delta)q_d{}^{1-\sigma}]^{-1} > 0 \end{aligned} \tag{3.28}$$

where the latter equality follows from setting $t_c = t_d$, in other words evaluating the derivative at the point of uniform commodity taxation. Result (3.28) simply states that an increase in the relative output price leads to higher consumer prices and therefore higher wage claim by the trade union.

Equipped with the results (3.21)-(3.28) we are ready to assess the sign of the employment effect of increased payroll tax in the non-polluting sector. Applying the derived signs of the derivatives to the right hand side of (3.20) reveals that the first and the second terms are negative whereas the third term is positive. In other words, with the relative output price fixed, the direct effect of the payroll tax is negative. The effect through the decreased relative price of the polluting output consists of a negative effect with a given wage rate and a positive effect through lower wages. Consequently, the total sign of (3.20) remains ambiguous.

For the total effect on employment to be negative it suffices to show that the sum of the second and the third terms on the right hand side of (3.20) - in other words the effect due to change in the relative output price - is non-positive. To show that this indeed is the case, we apply the chain rule to rewrite the sum of the second and third term

$$L_{qd}\left(\frac{dq_d}{d(1+s_c)}\right)+L_w\left(\frac{dw}{d(1+s_c)}\right)=\left[L_{qd}+L_w\frac{dw}{dq_d}\right]\left(\frac{dq_d}{ds_{cd}}\right)\left(\frac{ds_{cd}}{d(1+s_c)}\right) \tag{3.29}$$

According to (3.24) and (3.26) the sign of (3.29) is opposite to the sign of the formula within the square brackets. To determine the sign of that formula, we substitute (3.22), (3.23) and (3.28) for the respective elasticities to get

$$\begin{aligned} L_{qd}+L_w\frac{dw}{dq_d} &= \left(\frac{1}{1-\alpha}\right)\Phi_1 q_d^{\frac{1}{\Delta}-1}\left(1+q_d^{1/\Delta}\right)^{\frac{-\beta}{1-\alpha}}-\left(\frac{1}{1-\alpha}\right)\Phi_1 w^{-1}\left(1+q_d^{1/\Delta}\right)^{\frac{-\beta}{1-\alpha}+1}\left(\frac{dw}{dq_d}\right) \\ &= \left(\frac{1}{1-\alpha}\right)\Phi_1 q_d^{\frac{1}{\Delta}-1}\left(1+q_d^{1/\Delta}\right)^{\frac{-\beta}{1-\alpha}}\left[1-\left(1+q_d^{1/\Delta}\right)q_d^{-1/\Delta+1-\sigma}(1-\delta)^{\sigma}[\delta^{\sigma}+(1-\delta)q_d{}^{1-\sigma}]^{-1}\right] \\ &= \left(\frac{1}{1-\alpha}\right)\Phi_1 q_d^{\frac{1}{\Delta}-1}\left(1+q_d^{1/\Delta}\right)^{\frac{-\beta}{1-\alpha}}\left[1-\frac{1+q_d^{-1/\Delta}}{1+\left(\frac{\delta}{1-\delta}\right)^{\sigma}q_d{}^{\sigma-1}}\right] \end{aligned} \tag{3.30}$$

The sign of (3.30) is dictated by the term within the square brackets. At the starting point of uniform commodity and payroll taxation, the equilibrium price of the polluting output (2.28) becomes

$$q_d=\left(\frac{1-\delta}{\delta}\right)^{\sigma\Delta/(\Delta\sigma+\alpha+\beta)}$$

Substituting this for the relative price within the square brackets in (3.30) yields

$$\begin{aligned} 1-\frac{1+q_d^{-1/\Delta}}{1+\left(\frac{\delta}{1-\delta}\right)^{\sigma}q_d{}^{\sigma-1}} &= 1-\left[1+\left(\frac{1-\delta}{\delta}\right)^{-\sigma/(\Delta\sigma+\alpha+\beta)}\right]\left[1+\left(\frac{\delta}{1-\delta}\right)^{\sigma}\left(\frac{1-\delta}{\delta}\right)^{\sigma\Delta(\sigma-1)/(\Delta\sigma+\alpha+\beta)}\right]^{-1} \\ &= 1-\left[1+\left(\frac{1-\delta}{\delta}\right)^{-\sigma/(\Delta\sigma+\alpha+\beta)}\right]\left[1+\left(\frac{1-\delta}{\delta}\right)^{-\sigma/(\Delta\sigma+\alpha+\beta)}\right]^{-1} \\ &= 0 \end{aligned} \tag{3.31}$$

Thus, by (3.31), (3.30) and (3.29) are zero. The sign of (3.20) is then determined by the first term on the right hand side and is therefore negative. Intuitively, the negative direct effect on employment of a decrease in the relative price of the polluting output is just overcome by the induced decrease in wages. Thus, the total effect of an increase in the payroll tax of the non-polluting sector is determined solely by the direct effect with fixed relative output prices. The latter is proved negative by (3.21) and (3.24). We conclude that an increase (decrease) in the payroll tax of non-polluting sector decreases (increases) employment in the model.

3.2.2 Effects on the Environment

Above we showed that the payroll in the non-polluting sector has a negative effect on total employment. We now proceed to derive the effect of an increase in the payroll tax of the non-polluting sector on the equilibrium level of the polluting output and environmental quality.

For that purpose we first recall equation (2.3) defining the equilibrium level of the polluting output and rewrite it in terms of net wage rather than the producer price of labour to get

$$Y_d = \Lambda(1+s_d)^{-\alpha/\Delta}\left[q_d^{\alpha+\beta} q_k^{-\beta} w^{-\alpha}\right]^{1/\Delta} \tag{3.32}$$

Then substituting (2.32') for the equilibrium price of capital in (3.32) yields

$$Y_d = \Lambda\left(\Omega_k K_0^{-1}\right)^{\frac{-\beta}{1-\alpha}} w^{\frac{-\alpha}{1-\alpha}} (1+s_d)^{\frac{-\alpha}{1-\alpha}} q_d^{\frac{\alpha+\beta}{\Delta}} \left[s_{cd}^{\alpha/\Delta} + q_d^{1/\Delta}\right]^{-\frac{\beta}{1-\alpha}} \tag{3.33}$$

which defines the level of polluting output as a function of wages, relative price of the outputs and sector specific payroll tax rates. Differentiating (3.33) then gives

$$\frac{dY_d}{d(1+s_c)} = Y_s\left(\frac{ds_{cd}}{d(1+s_c)}\right) + Y_{qd}\left(\frac{dq_d}{d(1+s_c)}\right) + Y_w\left(\frac{dw}{d(1+s_c)}\right) \tag{3.34}$$

which decomposes the effect of payroll tax on the level of polluting output into three components. The first term on the right hand side reflects the direct effect with the relative price of the outputs and wages unchanged. The second term reflects the effect through relative price of the two outputs for a given wage rate. Finally, the third term gives the additional effect through wage formation. To determine the total effect of an increase in the payroll tax in the non-polluting sector, we must derive the sign of expression (3.34).

Again, we start with the partial derivatives. Differentiating (3.33) with respect to the payroll tax rate in the non-polluting sector gives

$$Y_s \equiv \partial Y_d/\partial s_{cd} = -\frac{\alpha\beta}{\Delta(1-\alpha)}\Phi_2 s_{cd}^{\frac{\alpha}{\Delta}-1} q_d^{\frac{\alpha+\beta}{\Delta}}\left[s_{cd}^{\alpha/\Delta} + q_d^{1/\Delta}\right]^{\frac{-\beta}{1-\alpha}-1} < 0 \tag{3.35}$$

where

$$\Phi_2 \equiv \Lambda\left(\Omega_k K_0^{-1}\right)^{\frac{-\beta}{1-\alpha}} w^{\frac{-\alpha}{1-\alpha}}(1+s_d)^{\frac{-\alpha}{1-\alpha}} > 0$$

According to (3.35), a decrease in the payroll tax of the non-polluting sector has a negative effect on the polluting output given that output price and wages remain unchanged. Intuitively, the producer price of labour drops in the non-polluting sector increasing employment and the return on capital. Increased capital price dampens output in the polluting sector.

Similarly, differentiating (3.33) with respect to the relative price of the outputs gives

$$Y_{qd} \equiv \partial Y_d/\partial q_d = \Phi_2\left\{\tfrac{\alpha+\beta}{\Delta}q_d^{\frac{\alpha+\beta}{\Delta}-1}\left[s_{cd}^{\alpha/\Delta}+q_d^{1/\Delta}\right]^{\frac{-\beta}{1-\alpha}} - \tfrac{\beta}{\Delta(1-\alpha)}q_d^{\frac{1+\alpha+\beta}{\Delta}-1}\left[s_{cd}^{\alpha/\Delta}+q_d^{1/\Delta}\right]^{\frac{-\beta}{1-\alpha}-1}\right\}$$

$$= \tfrac{1}{\Delta(1-\alpha)}\Phi_2 q_d^{\frac{\alpha+\beta}{\Delta}-1}\left[s_{cd}^{\alpha/\Delta}+q_d^{1/\Delta}\right]^{\frac{-\beta}{1-\alpha}}\left\{\alpha\Delta+\beta\left[1-q_d^{\frac{1}{\Delta}}\left(s_{cd}^{\alpha/\Delta}+q_d^{1/\Delta}\right)^{-1}\right]\right\} > 0 \tag{3.36}$$

Equation (3.36) simply states that an increase in the producer price of the polluting output increases the equilibrium level of the polluting output, given that wages are fixed. Finally, differentiating (3.33) with respect to the net wage gives

$$Y_w \equiv \partial Y_d/\partial w = -\tfrac{\alpha}{1-\alpha}\Phi_2 q_d^{\frac{\alpha+\beta}{\Delta}} w^{-1}\left[s_{cd}^{\alpha/\Delta}+q_d^{1/\Delta}\right]^{\frac{-\beta}{1-\alpha}} < 0 \tag{3.37}$$

implying a negative effect of a general wage hike on polluting output.

The signs of the derivatives within brackets on the right hand side of (3.34) have already been derived above in (3.24), (3.25) and (3.27) and are listed here for convenience

$$\frac{ds_{cd}}{d(1+s_c)} < 0, \frac{dq_d}{d(1+s_c)} < 0, \frac{dw}{d(1+s_c)} < 0$$

Applying these and the signs of the partial derivatives derived in (3.35)-(3.37) to (3.34) reveals that the first and the third terms on the right hand side of (3.34) are positive while the second term is negative. Intuitively, the positive direct effect is fortified by the positive effect due to dropping wages. However, the drop in the relative producer price of output causes an opposite, depressing effect on the level of polluting output. Thus, the sign of the overall effect remains ambiguous.

To find the sign of the total effect, we further substitute equations (2.50) and (2.36) for the wage rate and CPI, respectively in (3.33) to get

$$Y_d = \Phi_3 q_d^{\frac{\alpha+\beta}{\Delta}}\left[s_{cd}^{\alpha/\Delta}+q_d^{1/\Delta}\right]^{-\frac{\beta}{1-\alpha}}\left[\delta^{\sigma}(1+t_c)^{1-\sigma}+(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d{}^{1-\sigma}\right]^{\frac{-\alpha}{(1-\alpha)(1-\sigma)}} \tag{3.38}$$

where

$$\Phi_3 \equiv \Lambda\left(\Omega_k K_0^{-1}\right)^{\frac{-\beta}{1-\alpha}}[\alpha(1-t_L)b^{-1}]^{\frac{\alpha}{1-\alpha}}(1+s_d)^{\frac{-\alpha}{1-\alpha}} > 0$$

is a positive constant. Equation (3.38) defines the equilibrium level of the polluting output as a function of the relative output price and the payroll tax rates only.[30] Differentiating (3.38) gives

$$\frac{dY_d}{d(1+s_c)} = \hat{Y}_s\left(\frac{ds_{cd}}{d(1+s_c)}\right) + \hat{Y}_{qd}\left(\frac{dq_d}{d(1+s_c)}\right)$$
$$= \left[\hat{Y}_s + \hat{Y}_{qd}\left(\frac{dq_d}{ds_{cd}}\right)\right]\left(\frac{ds_{cd}}{d(1+s_c)}\right) \qquad (3.39)$$

where the latter equality follows from the substitution of (3.25). The signs of the other two derivatives in (3.39) have been derived above in (3.24) and (3.26)

$$\frac{ds_{cd}}{d(1+s_c)} < 0, \frac{dq_d}{ds_{cd}} > 0$$

To find the sign of (3.39) we now derive the signs of the two partial derivatives. First, differentiating (3.38) with respect to the ratio of the payroll taxes and evaluating at the point of uniform commodity and payroll tax rates yields

$$\hat{Y}_s \equiv \partial Y_d / \partial s_{cd}$$
$$= -\frac{\alpha\beta}{\Delta(1-\alpha)}\Phi_3 q_d^{\frac{\alpha+\beta}{\Delta}}(1+t)^{-\frac{\alpha}{1-\alpha}}\left(1+q_d^{1/\Delta}\right)^{-\frac{\beta}{1-\alpha}-1}[\delta^\sigma + (1-\delta)^\sigma q_d{}^{1-\sigma}]^{\frac{-\alpha}{(1-\alpha)(1-\sigma)}} < 0 \qquad (3.40)$$

where t stands for the uniform rate of commodity taxation $t_c = t_d = t$. Equation (3.40) merely restates the result (3.35) that a decrease in the payroll tax ix of the

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30 Note that we might have substituted for the wage rate directly, but we found expression (6.17) useful for interpretation and gaining insight into the underlying mechanism.

non-polluting sector has a negative effect on the polluting output given that output price and wages remain unchanged.

Differentiating (3.38) with respect to the ratio of the payroll taxes yields

$$\begin{aligned}\hat{Y}_{qd} &\equiv \partial Y_d/\partial q_d \\ &= \Phi_3\left\{\Psi_1'(q_d)\Psi_2(q_d)\Psi_3(q_d)+\Psi_1(q_d)\left[\Psi_2'(q_d)\Psi_3(q_d)+\Psi_2(q_d)\Psi_3'(q_d)\right]\right\} \\ &= \Phi_3\Psi_1'\Psi_2\Psi_3\left\{1+\Psi_1\left(\Psi_1'\right)^{-1}\left[\Psi_2'(\Psi_2)^{-1}+\Psi_3'(\Psi_3)^{-1}\right]\right\}\end{aligned} \qquad (3.41)$$

where

$$\Psi_1(q_d) \equiv q_d^{\frac{\alpha+\beta}{\Delta}} > 0$$

$$\Psi_2(q_d) \equiv \left[s_{cd}^{\alpha/\Delta}+q_d^{1/\Delta}\right]^{-\frac{\beta}{1-\alpha}} > 0$$

$$\Psi_3(q_d) \equiv \left[\delta^{\sigma}(1+t_c)^{1-\sigma}+(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d{}^{1-\sigma}\right]^{\frac{-\alpha}{(1-\alpha)(1-\sigma)}} > 0$$

are functions in the relative output prices and Ψ_i' refer to the respective derivatives

$$\Psi_1'(q_d) \equiv \tfrac{\alpha+\beta}{\Delta}q_d^{\frac{\alpha+\beta}{\Delta}-1} > 0$$

$$\Psi_2'(q_d) \equiv -\tfrac{\beta}{\Delta(1-\alpha)}q_d^{1/\Delta-1}\left[s_{cd}^{\alpha/\Delta}+q_d^{1/\Delta}\right]^{-\frac{\beta}{1-\alpha}-1} < 0$$

$$\Psi_3'(q_d) \equiv \tfrac{-\alpha}{(1-\alpha)}(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d{}^{-\sigma}\left[\delta^{\sigma}(1+t_c)^{1-\sigma}+(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d{}^{1-\sigma}\right]^{\frac{-\alpha}{(1-\alpha)(1-\sigma)}-1} < 0$$

With the signs of the formulas derived above, the sign of (3.41) is ambiguous and determined by the sign of the formulas within the brackets. Substituting the explicit formulas into (3.41) and evaluating at the point of uniform commodity and payroll tax rates yields

$$\hat{Y}_{qd} = \Phi_3\Phi_4\left\{1 - \frac{1}{(1-\alpha)(\alpha+\beta)}\left[\beta q_d^{1/\Delta}\left(1+q_d^{1/\Delta}\right)^{-1} + \alpha\Delta(1-\delta)^{\sigma}q_d^{1-\sigma}\left(\delta^{\sigma}+(1-\delta)^{\sigma}q_d^{1-\sigma}\right)^{-1}\right]\right\}$$

$$= \Phi_3\Phi_4\left\{1 - \frac{\varphi(\beta+\alpha\Delta)}{(1-\alpha)(\alpha+\beta)}\right\}$$

$$= \Phi_3\Phi_4\{1-\varphi\} > 0 \qquad (3.42)$$

where

$$\Phi_4 \equiv \Psi_1^{'}\Psi_2\Psi_3 > 0$$

and

$$\varphi \equiv \left[1+\left(\frac{1-\delta}{\delta}\right)^{-\sigma/(\Delta\sigma+\alpha+\beta)}\right]^{-1} < 1$$

$$= q_d^{1/\Delta}\left(1+q_d^{1/\Delta}\right)^{-1}$$

$$= (1-\delta)^{\sigma}q_d^{1-\sigma}\left(\delta^{\sigma}+(1-\delta)^{\sigma}q_d^{1-\sigma}\right)^{-1} \qquad (3.43)$$

The last two equalities in (3.43) follow from substituting the formula (2.28) for the equilibrium price of polluting output at the starting point with uniform tax rates across sectors. Thus, by (3.42) the total effect of payroll tax through the change in the relative output price is positive. In other words, the direct effect of output price dominates the opposite effect due to the induced change in the wage rate. Applying the positive sign of (3.42) to (3.39) reveals that the overall effect of increased payroll tax remains ambiguous as the direct effect with fixed output prices is negative as showed in (3.40).

To find the sign of the overall effect, we substitute the explicit formulas into (3.39). The sign of (3.39) is opposite to the sign of the term within the square brackets. Substituting (3.40) and (3.43) and evaluating at the point of uniform commodity and payroll tax rates, we may rewrite the term within the square brackets in (3.39)

$$\hat{Y}_s + \hat{Y}_{qd}\left(\frac{dq_d}{ds_{cd}}\right) = -\Phi_5\left[\frac{\beta}{1-\alpha} - \frac{(\alpha+\beta)(1-\varphi)}{\Delta\sigma+\alpha+\beta}\left(1+q_d^{1/\Delta}\right)\right]$$
$$= -\Phi_5\left[\frac{\beta}{1-\alpha} - \frac{(\alpha+\beta)}{\Delta\sigma+\alpha+\beta}\right] \tag{3.44}$$

where

$$\Phi_5 \equiv \tfrac{\alpha}{\Delta}\Phi_3(1+t)^{-\frac{\alpha}{1-\alpha}} q_d^{\frac{\alpha+\beta}{\Delta}}\left(1+q_d^{1/\Delta}\right)^{-\frac{\beta}{1-\alpha}-1}\left[\delta^\sigma + (1-\delta)^\sigma q_d{}^{1-\sigma}\right]^{\frac{-\alpha}{(1-\alpha)(1-\sigma)}} > 0$$

According to (3.44)

$$\hat{Y}_s + \hat{Y}_{qd}\left(\frac{dq_d}{ds_{cd}}\right) \leq 0 \Leftrightarrow \sigma \geq \frac{\alpha+\beta}{\beta} \equiv \sigma^* \tag{3.45}$$

Thus, the sign of (3.39) depends on the elasticity of substitution between the two consumption categories in consumption. The sign of (3.39) and the effect of the payroll tax in the non-polluting sector on polluting output is positive if and only if the elasticity of substitution is higher than some critical value, σ^*. Intuitively, a sufficiently high substitution elasticity is required for the sector specific payroll tax to have opposite effects on the equilibrium levels of the two outputs. With relatively low substitution elasticity, the effect of the sector specific payroll tax becomes similar to that of labour income tax depressing output in both sectors. In that case, even the payroll tax in the non-polluting sector turn out to be a "green tax" in the sense that its increase can be justified on environmental grounds.

Taking a closer look at (3.45) we notice that the critical value of substitution elasticity depends on the share parameters of labour and capital in production. For a given share of profits $(1-\alpha-\beta)$, the critical value depends positively on the share of labour in value added, α. The larger the share of labour, the more weight the second, positive, term gets within the square brackets on the right hand side of (3.39). This is because the change in the relative price of the two outputs due to a change in the sector specific payroll tax is larger the higher is the share of labour in value added. On the other hand, the change in the relative price of the two outputs due to a change in the sector specific payroll tax depends negatively on the elasticity of substitution between the outputs in consumption. Thus, even for high labour shares, there exists a critical elasticity of substitution that will reverse the sign of the effect.[31]

We conclude that an increase in the payroll tax of the non-polluting sector improves (worsens) the level of environmental quality in the model if the elasticity of substitution is lower (higher) than some critical value. This critical value depends positively on the share of labour in value added.

To sum up, the comparative statics show that the payroll tax of the non-polluting sector has a negative effect on employment. Therefore, we cannot tell, a priori, the effect on employment of a "green" tax reform where an increase in the environmental tax is compensated for by a cut in the payroll tax of the non-polluting sector. As for the environment, the effect of a "green" reform is ambiguous as long as $\sigma < \sigma^*$, i.e. elasticity of substitution is low enough. However, if the elasticity of substitution between the two consumption categories exceeds the critical level, a "green" tax reform that cuts the payroll tax of non-polluting sector to compensate for the increased environmental tax will always improve the environment.

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[31] The dependency of the output price change on the labour share and elasticity of substitution parameters can be verified by differentiating the expression (2.28') for the equilibrium price of polluting output.

4. Revenue Neutral Change in the Tax Structure

In the previous section we considered the effects of various tax instruments in isolation, and noticed that the both labour taxes and the environmental tax are harmful to employment. The labour income tax and the environmental tax also serve to reduce pollution. The effect of the non-polluting sector payroll tax on pollution depends on the substitutability of the two outputs in consumption. Equipped with these results, we now proceed to examine the effects of a revenue neutral switch in the tax structure. In particular, we are interested in what happens to employment and the environment if we increase the environmental tax, and simultaneously decrease the tax rate on labour income or payroll tax in the non-polluting sector, so as to keep the public revenues intact. In what follows we refer to such a change in the tax policy as a "green" tax reform.

4.1 Defining Revenue Neutrality

From the policy point of view it is often useless to know that lowering a particular tax would improve employment or efficiency. This is because public expenditure has to be financed somehow, and lowering one tax would necessitate an increase in another, possibly an even more harmful one. This is why it is interesting to consider the effects on key economic variables of changes in the tax structure that leave public revenues intact. The ability to raise revenue provides a yardstick for making choice among alternative tax instruments each possessing adverse economic effects.

Since the final purpose of revenues is to finance public expenditure (e.g. the provision of health services), preserving nominal revenues is not necessarily sufficient to leave the level of provision intact. This is because changes in the tax rates do affect relative prices and thus the cost of public provision. To overcome this caveat, we must either fix the level of public provision directly or fix revenue in real terms, deflated by an appropriate price index (for further discussion see Shoven and Whalley, 1977). In the present model, where revenues are used to finance transfers to consumers, it seems appropriate to deflate the revenues with CPI in order to arrive at transfers in real terms.

There is another aspect of the present framework that deserving of comment. Since the public transfers partly consist of unemployment benefits, it seems reasonable to fix the real revenue net of unemployment benefits. The idea here is that unemployment benefits can be thought of as an additional burden for the public sector, while other transfers (such as child allowances) constitute the true "public utility". Consequently, in comparing alternative tax instruments or systems, we need to consider not only their capability to raise gross revenue but also their effect on unemployment benefits.

According to these guidelines, we define the net revenue in real terms as

$$\hat{T} = TRp^{-1} \tag{4.1}$$

where TR are transfers as defined in (2.5)[32] and p is the consumer price index defined in (2.36).

4.2 Effect of a Green Tax Reform on Employment and the Environment

To analyse the tax reform, we first consider the effects on employment of the simultaneous changes in tax rates on labour income and the polluting output. Similar to section 3.1, we assume that the payroll tax rate is equal across sectors. Invoking the expression (3.1) for the aggregate employment and noting that tax parameters only enter the relative prices q_L and q_d we differentiate to get

$$dL = L_{ql} dq_L + L_{qd} dq_d \tag{4.2}$$

[32] To be exact, in (4.1) TR refer the transfers measured in terms of the non-polluting output, TR/qc.

Facing simultaneous changes in the tax rates on labour and the polluting output, we can derive changes in the relative prices of labour and the polluting output as follows

$$dq_L = q_{LL}d(1-t_L) + q_{LD}d(1+t_d)$$
$$dq_d = q_{DL}d(1-t_L) + q_{DD}d(1+t_d) \quad (4.3)$$

where q_{ij}, i=D,L refer to the relevant partial derivatives that have been derived in section 3.1. Substituting (4.3) in (4.2) and rearranging, gives

$$dL = [L_{ql}q_{LL} + L_{qd}q_{DL}]d(1-t_L) + [L_{ql}q_{LD} + L_{qd}q_{DD}]d(1+t_d) \quad (4.4)$$

for a change in the aggregate employment. Expression (4.4) decomposes the employment effect of a simultaneous tax rate change into four components. The two terms within the first square brackets reflect respectively the effect of labour income tax on the producer price of labour and on the relative producer price of the outputs. The two terms within the second square brackets similarly reflect the effect of environmental tax on the two producer prices.

Similar procedure can be used to derive the effects of simultaneous tax rate changes on the level of polluting output. Recalling the expression (3.13) for the equilibrium level of polluting output and differentiating gives

$$dY_d = Y_{ql}dq_L + Y_{qd}dq_d \quad (4.5)$$

Substituting (4.3) for the price changes and rearranging then yields

$$dY_d = [Y_{ql}q_{LL} + Y_{qd}q_{DL}]d(1-t_L) + [Y_{ql}q_{LD} + Y_{qd}q_{DD}]d(1+t_d) \quad (4.6)$$

which gives a decomposition that is the analogue of (4.4) for polluting output.

Turning back to expressions (4.4) and (4.6) we can now determine the sign of their components. The signs of the derivatives within the square brackets in (4.4) and (4.6) have already been derived in section 3.1 and are listed here for convenience

$$L_{ql} \equiv \frac{\partial L}{\partial q_L} < 0$$

$$L_{qd} \equiv \frac{\partial L}{\partial q_d} > 0$$

$$Y_{ql} \equiv \frac{\partial Y_d}{\partial q_L} < 0$$

$$Y_{qd} \equiv \frac{\partial Y_d}{\partial q_d} > 0$$

$$q_{LL} \equiv \frac{dq_L}{d(1-t_L)} < 0$$

$$q_{LD} \equiv \frac{\partial q_L}{\partial(1+t_d)} + \frac{\partial q_L}{\partial q_d}\frac{dq_d}{d(1+t_d)} > 0$$

$$q_{DL} \equiv \frac{dq_d}{d(1-t_L)} = 0$$

$$q_{DD} \equiv \frac{dq_d}{d(1+t_D)} < 0$$

Consequently, with $q_{DL} = 0$, the effect of labour income tax on employment and pollution comes solely through the producer price of labour and (4.4) reduces to

$$dL = [L_{ql}q_{LL}]d(1-t_L) + [L_{ql}q_{LD} + L_{qd}q_{DD}]d(1+t_d) \qquad (4.7)$$

Similarly, (4.6) reduces to

$$dY_d = [Y_{ql}q_{LL}]d(1-t_L) + [Y_{ql}q_{LD} + Y_{qd}q_{DD}]d(1+t_d) \qquad (4.8)$$

Now, consider a policy that increases tax rate on the polluting good, t_d and allows the tax rate on labour to adjust so as to keep the net revenue fixed in real terms. The effect of such a policy on the net revenue may be described as

$$d\hat{T} = -\hat{T}_{tl}d(1-t_L) + \hat{T}_{td}d(1+t_d) = 0 \qquad (4.9)$$

where $\hat{T}_{ti}$ is the partial derivative of real net revenue with respect to the tax rates on labour income and the polluting output, respectively. Rearranging (4.9) gives

$$d(1-t_L) = \frac{\hat{T}_{td}}{\hat{T}_{tl}} d(1+t_d) \tag{4.10}$$

which defines the change in the labour tax rate required to compensate for the increase in the environmental tax. Assuming that the two partial derivatives are positive,[33] the change in the labour tax rate must be negative.

Substituting the balanced budget constraint (4.10) into (4.7) and rearranging yields the condition for a positive employment effect after a revenue neutral switch in the tax structure

$$\frac{\hat{T}_{td}}{-L_{td}} > \frac{\hat{T}_{tl}}{L_{tl}} \tag{4.11}$$

where

$$L_{tl} \equiv L_{ql} q_{LL} > 0$$

$$L_{td} \equiv L_{ql} q_{LD} + L_{qd} q_{DD} < 0$$

are derivatives defined above.

The term on the left hand side of (4.11) is the ratio of the change in net revenue to the change in employment (in absolute value) caused by the environmental tax. The term on the right hand side of (4.11) is the ratio of the change in net revenue to the change in employment caused by labour income tax. Condition (4.11) states that for employment to improve, the ratio of the change in net revenue to the change in employment caused by the environmental tax has to be greater than the

[33] This is somewhat stronger requirement than assuming a upward sloping "Dupuit-Laffer curve" for that particular tax (see e.g. Bovenberg and de Mooij, 1994, Koskela & Schöb, 1997) . A sufficient condition can be shown to require that initial tax rates and the share of labour in value added are not too high.

corresponding ratio for labour income tax. Intuitively, environmental tax has to be capable of raising more revenue per lost unit of employment.

Rearranging (4.11) and writing it out in terms of elasticities yields

$$\frac{\hat{\tau}_{td}}{\hat{\tau}_{tl}} > \frac{\omega_{td}}{\omega_{tl}} + \frac{\varepsilon_{qd}\eta_{td}}{\varepsilon_{ql}\omega_{tl}} \qquad (4.11')$$

where $\hat{\tau}_{ti}$ is the elasticity of net revenue with respect to the corresponding tax rate, ω_{ti} is the elasticity of net wages with respect to the corresponding tax rates, ε_{qi} is the elasticity of employment with respect to the corresponding producer price and η_{td} is the elasticity of relative output price with respect to the tax rate on polluting output (see Appendix 6 for details).

Condition (4.11') states that for employment to improve, the ratio of elasticity of net revenue with respect to the environmental tax to the elasticity with respect to the labour income tax must exceed the ratio of the corresponding elasticities of employment. The latter ratio is decomposed into the ratio elasticity of net wages and an additional term reflecting the strength of the employment effect of the environmental tax through the output price relative to the employment effect of labour income tax through wages. Condition (4.11') is a generalisation of that derived by Koskela and Schöb (1997) in a partial equilibrium framework. Since Koskela and Schöb assume fixed output prices, the latter term on the right hand side of (4.11') is zero in their analysis. In our case, the second term on the right hand side is positive and the employment improving ratio of revenue elasticities of the two tax rates becomes higher as the change in the relative output price is taken account of. Intuitively, allowing for general equilibrium repercussions calls for better performance from the environmental tax in terms of raising revenue. This is because a drop in the relative output price due to increased environmental tax causes an additional negative effect on employment.

For environmental effects, substituting the balanced budget constraint (4.10) into (4.8) and rearranging, yields the condition for an improvement in the environmental quality after a revenue neutral switch in the tax structure

$$\frac{\hat{T}_{td}}{-Y_{td}} < \frac{\hat{T}_{tl}}{Y_{tl}} \tag{4.12}$$

where

$$Y_{td} \equiv Y_{ql}q_{LD} + Y_{qd}q_{DD} < 0$$
$$Y_{tl} \equiv Y_{ql}q_{LL} > 0$$

Condition (4.12) is the environmental counterpart of (4.11) and states that for the environment to improve, the ratio of the change in net revenue to the change in polluting output caused by the environmental tax has to be less than the corresponding ratio for labour income tax. Intuitively, environmental tax has to be capable of reducing more pollution per unit of revenue raised.

Rearranging (4.12) and writing it in terms of elasticities yields

$$\frac{\hat{\tau}_{td}}{\hat{\tau}_{tl}} < \frac{\omega_{td}}{\omega_{tl}} + \frac{\psi_{qd}\eta_{td}}{\psi_{ql}\omega_{tl}} \tag{4.12'}$$

where $\hat{\tau}_{ti}$ is the elasticity of net revenue with respect to the corresponding tax rate and ω_{ti} is the elasticity of net wages with respect to the corresponding tax rate, η_{td} is the elasticity of relative output price with respect to the tax rate on polluting output, as before, and ψ_{qi} is the elasticity of polluting output with respect to the relevant producer price.

Condition (4.12') is the environmental counterpart of (4.11') and states that for the environment to improve, the ratio of elasticity of net revenue with respect to the environmental tax to the elasticity with respect to the labour income tax must be less than the ratio of the corresponding elasticities of polluting output. The latter ratio is decomposed into the ratio of wage elasticities and the output elasticities similar to (4.11').

Bringing together (4.11') and (4.12') produce a condition for a simultaneous improvement in employment and environmental quality

$$\frac{\omega_{td}}{\omega_{tl}} + \frac{\varepsilon_{qd}\eta_{td}}{\varepsilon_{ql}\omega_{tl}} < \frac{\hat{\tau}_{td}}{\hat{\tau}_{tl}} < \frac{\omega_{td}}{\omega_{tl}} + \frac{\psi_{qd}\eta_{td}}{\psi_{ql}\omega_{tl}} \tag{4.13}$$

According to (4.13), for the double dividend to arise, the environmental tax has to raise more revenue per lost unit of employment and reduce more polluting output per unit of revenue raised than the labour income tax. Failing to satisfy these conditions will cause either employment or the environment or both to deteriorate after a revenue neutral switch in favour of the environmental tax.

A necessary condition for (4.13) to hold is that the right hand side is greater than the left hand side, implying

$$\frac{\psi_{qd}}{\varepsilon_{qd}} > \frac{\psi_{ql}}{\varepsilon_{ql}} \tag{4.14}$$

Condition (4.14) is a necessary condition for a double dividend to rise in the model. It says that the ratio of the elasticity of polluting output to the elasticity of employment with respect to the relative price of output has to be greater than the corresponding ratio of elasticities with respect to the relative price of labour. Intuitively, for a switch from labour to commodity taxes to be capable of producing higher employment and lower pollution, output price has to have a relatively stronger effect on polluting output and weaker effect on employment than labour price.

Generally, whether conditions (4.11), (4.12) and in particular (4.13) are satisfied or not, depends on the values of model parameters in a relatively complicated way.

We therefore return to the problem in section 5 where we run numerical simulations of the model with some plausible parameter values.

So far we have considered a revenue preserving reform where higher environmental tax is compensated for by a lower labour income tax. It should be noted that conditions (4.11) and (4.12) are equally valid for the case where increase in the environmental tax is accompanied by a decrease in the payroll tax of the non-polluting sector only. However, with the sector specific payroll tax lowered, a special case arises where the improvement in environmental quality can be guaranteed. If the elasticity of substitution between the consumption categories is large enough, $\sigma > \sigma*$, condition (4.12) for improved environmental quality becomes

$$\frac{\hat{T}_{td}}{Y_{td}} < \frac{\hat{T}_{sc}}{Y_{sc}} \qquad (4.12'')$$

where $\hat{T}_{sc}$ is the partial derivative of real net revenue with respect to the payroll tax rate in the non-polluting sector and

$$Y_{sc} \equiv \left[\hat{Y}_s + \hat{Y}_{qd}\left(\frac{dq_d}{ds_{cd}}\right)\right]\left(\frac{ds_{cd}}{d(1+s_c)}\right) \qquad (3.39')$$

is the derivative of polluting output with respect to the payroll tax in the non-polluting sector defined in (3.39). Then by (3.45), as $\sigma > \sigma*$, (3.39') is positive and (4.12') holds irrespective of the magnitude of the derivatives since the left hand side is negative and the right hand side is positive.

Before turning to numerical simulations, we consider another special case that has gained attention in the literature: the case where unemployment benefits are taxed at a rate equal to labour income tax. Then, it is straightforward to show that[34]

$$q_{LL} \equiv \frac{dq_L}{d(1-t_L)} = 0 \qquad (4.15)$$

[34] With wage income and unemployment benefits taxed equally, the term containing labour tax rate disappears from the wage equation (2.50). See Appendix 7 for details.

and (4.9) may be rewritten as

$$dL = [L_{ql}q_{LD} + L_{qd}q_{DD}]d(1+t_d) < 0 \tag{4.16}$$

where $d(1+t_d) > 0$ by definition and the term inside the square brackets is negative. Thus, according to (4.16), if unemployment benefits are taxed equally with labour income, a revenue neutral[35] switch from labour income tax to the environmental tax will always reduce employment. Intuitively, in this case the union is interested only in gross earnings, and reduced income tax rate have no effect on the preferred wage rate. However, an increase in the environmental tax puts an upward pressure on wages which tends to reduce employment. This effect is reflected by the first term inside the square brackets on the right hand side of (4.16). Moreover, higher environmental tax changes the relative producer price of the two goods with a further adverse effect on employment. The latter effect is captured by the second term within the square brackets.[36]

Holmlund et al (1989) have shown that if the utilities of the union members are state independent and exhibit constant relative risk aversion, labour income tax changes have no effect on the wage rate if unemployment benefits are taxed equally with labour income. This result applies in our model making labour tax non-distortionary and thus a desirable device for collecting revenues.

Turning to the environmental effects, substitution of (4.15) into (4.8) gives

$$dY_d = [Y_{ql}q_{LD} + Y_{qd}q_{DD}]d(1+t_d) < 0 \tag{4.17}$$

where the sign follows from result (3.17). Thus, if unemployment benefits are taxed equally with labour income, a revenue neutral switch from labour income tax to the

[35] Actually, we have not exactly checked for revenue neutrality since the result holds for any policy where environmental taxes are increased and income taxes are reduced.

[36] Result (4.16) is in line with that derived by Koskela & Schöb, 1997 in a partial equilibrium model with labour as the single input.

environmental tax will always reduce pollution and consequently improve the environment. Intuitively, as labour income tax becomes non-distortionary, lowering it has no adverse effect on the environment and a "green dividend" is guaranteed.

In conclusion, we have characterised the conditions under which either employment or environment or both would improve after a revenue neutral switch from labour taxes to the environmental tax. Except for some special cases, we cannot tell whether a revenue neutral "green" tax reform will improve employment or environmental quality in the model. To find out about the sign and magnitude of the effects of such a reform, we parametrise the model and solve it numerically in the next section.

5. Simulations with a Numerical Model

In this section we proceed to parametrise the model and solve it numerically to determine the effects of tax policy changes under some plausible parameter values. The method also allows us to assess the magnitude of changes in the key variables. The modelling approach, referred to as the computable general equilibrium (CGE) models is discussed in Appendix 8.

5.1 Implementation of the Model

The numerical version of the model is implemented by programming the model equations derived in section 2, and letting the computer iteratively solve for the equilibrium prices and the corresponding quantities.[37] To solve for the endogenous variables, the exogenous variables of the model must be given some numerical values. The exogenous variables consist of the parameters of the production function and the household utility function, various tax rates and the total stock of capital and labour force.

The benchmark values for the exogenous model parameters are presented in table 5.1. The production share parameter of labour in (2.1) is one third for both sectors and the share parameter of capital is 0.57, leaving a 10 per cent margin for profits. These parameter values imply a sectoral constant output own price labour demand elasticity of -0.6, which is roughly in line with empirical estimates (e.g. Tossavainen, 1998). As for the preferences, the share parameter of non-polluting output in (2.13) is assumed to be 0.7. The elasticity parameter in (2.13) takes value 0.5, implying elasticity of substitution in consumption being equal to 2, which is the average used by Törmä and Rutherford (1993) for the "Armington elasticities" of various output categories. These preference parameters imply roughly a 20 per cent share of the polluting consumption of the total expenditure at the benchmark. For the tax parameters, we assume a flat 10

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37 The numerical model is implemented using GAMS programming package. GAMS allows one to write down the equations in the conventional algebraic form and has a set of built in solvers suitable for dealing with non-linear problems. The detailed program code is presented in Appendix 9.

per cent rate for labour and capital income tax, payroll tax on labour and consumption tax on the two output categories.[38] These tax rates imply a 20 per cent total output share of public expenditure at the benchmark.

Furthermore, we fix a given unemployment rate at the benchmark and determine the level of unemployment benefit paid by the government necessary for producing that rate of unemployment with the assumed structure of wage formation. In counterfactual tax policy simulations, the per head real unemployment benefit is fixed at the benchmark level. The unemployment rate is assumed to lie at 10 per cent at the benchmark.

Table 5.1 The benchmark values of exogenous model parameters

technology parameters		
α	0.33	share parameter of labour
β	0.57	share parameter of capital
preference parameters		
δ	0.70	share parameter of non-polluting consumption
γ	0.50	substitution parameter in consumption
tax parameters		
t_L	0.10	labour income tax rate
t_k	0.10	capital income tax rate
s_i	0.10	payroll tax rate i=C,D
t_i	0.10	commodity tax rate i=C,D

Given the exogenous parameters and some initial stock of capital and total labour force,[39] the model can be solved for a benchmark equilibrium. By exogenously

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38 In order to satisfy the assumption of positive partial derivatives in (4.9), initial tax rates and the share of labour in value added must be set relatively low. With higher tax rates the "Laffer curve" for labour income tax becomes downward sloping and revenue neutrality requires an increase rather than a decrease in the labour income tax.

39 The magnitude of the initial capital stock and the labour force does not play a role in tax policy simulations, so we are free to choose any two positive values to represent the benchmark.

changing the tax parameters we can then solve for counterfactual equilibria and do the comparative static analysis between the different tax policies.

5.2 Simulations of Uncompensated Tax Rate Changes

Starting from the initial equilibrium, we first simulate the effects of uncompensated changes in the tax rates on labour income and on the polluting consumption. The results of the simulations where tax rate on labour income was increased from the initial 10 to 11 percent are shown in the first column of table 5.2. Employment drops considerably, by 1.6 per cent, due to a rise in the product wage in both sectors.[40] This corresponds to an increase in the unemployment rate to 11.5 from the original 10 per cent. With full employment of capital, output falls along with employment, resulting in less environmental damage and lower consumption. It is worth noting that the negative effect on pollution of the labour income tax is relatively strong. Thus, labour income tax effectively serves as a "green tax."

Table 5.2. Simulation results from the increased tax rates on labour and polluting consumption. Net revenue refers to the total tax receipts minus unemployment benefits, measured in real terms. All entries are percentage changes from the benchmark level

	increase in labour tax	increase in environmental tax
employment	-1.6	-0.2
pollution	-0.5	-1.3
consumption	-0.5	-0.1
net revenue	0.2	0.5

The results of the simulations where tax rate on the polluting consumption good was increased from 10 to 11 per cent are shown in the second column of table 5.2. An increase in the environmental tax affects the wage rate only through its effect on the

[40] The elasticity of employment with respect to the labour income tax implied by the model is thus -0.16 , which corresponds to the upper limit reported by Holm et al (1995). That the effect in the present model tends to be stronger than in partial equilibrium models is partly due to allowing for changes in the level of output.

price index. Thus the rise in the producer price of labour remains moderate. The product wage increases slightly more in the polluting sector where the producer price of output drops. The structure of output is shifted towards the non-polluting output, which explains why pollution declines relatively more than employment and consumption.

5.3 Simulations of a Green Tax Reform

To simulate a revenue neutral switch from labour income taxes to environmental taxes, we increased the tax rate on the polluting output from 10 to 11 per cent, fixed the total revenue net of unemployment benefits at the benchmark level and allowed the tax rate on labour income to adjust accordingly. We first simulate the special case already discussed in section 4: unemployment benefits are taxed equally with labour income. The results from simulation are presented in the first column of table 5.3, and confirm the analytically derived results.

Table 5.3. Simulation results from a revenue neutral tax reform with alternative assumptions concerning the tax treatment of unemployment benefits. All entries except tax rates are percentage changes from the benchmark level

	benefit taxed	benefit exempted
employment	-0.2	4.3
pollution	-1.3	0.2
consumption	-0.1	1.4
labour tax rate	9.6	7.3

It is shown in appendix 7 that if unemployment benefits are taxed equally with labour income, the tax rate on labour income disappear from the wage equation. Intuitively, the union becomes interested in the gross compensation since tax treatment of the employed and unemployed will be equal. However, with low elasticity of labour supply (in our model zero) this turns labour tax into a very attractive way of collecting revenues (indeed, in our model labour tax becomes non-distortionary). This is why a switch from labour to the environmental tax has undesirable effects on employment and consumption in the first column of table 5.3.

Next, we run a similar tax policy simulation in the original setting where unemployment benefits are exempted from income tax. The results that we were unable to determine analytically are presented in the second column of table 5.3. If unemployment benefits are totally exempted (or taxed less than labour income), the tax rate on labour income enters the union's wage setting equation (see Appendix 7). In our specification, an increase in the tax rate is fully reflected in the producer price of labour, and employment reduces accordingly.[41] With a fixed supply and full employment of capital, reduced employment of labour leads to a lower output and a lower return on capital. Thus, revenues from other taxes tend to drop and labour tax becomes inefficient at collecting extra revenues. In such circumstances a moderate increase in the environmental tax enables a considerable drop in the labour income tax that potentially leads to lower wages and higher employment.

Simulation results with unemployment benefits exempted from income tax are presented in the second column of table 5.3. The increase in employment is considerable, 4.3 per cent from the benchmark level. In terms of unemployment rate this means a drop to 6.1 from the original 10 per cent. It should be noted that the relative change in the labour income tax rate is remarkable, roughly a fourth. This is partly due to the relatively large tax base of the environmental tax, but also because of increased revenues from other taxes, and a drop in the total revenue collected as a consequence of lower unemployment benefits. Consequently, collecting the same net revenue with environmental tax is less harmful to economic activity. Unfortunately, environmental quality deteriorates along with the higher level of economic activity, so no double dividend arises here either.

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41 For a discussion on the wage response to tax changes in union models, see Holmlund et al (1989).

5.4 Simulations with Sector Specific Payroll Tax on Labour

Given the model structure, the real effects of a uniform payroll tax are identical to those of the labour income tax. This is easily verified by running a simulation where an introduction of a uniform payroll tax is compensated for by a revenue preserving drop in the income tax rate on labour. In such a simulation, the net wage, i.e. the wage rate net of the payroll tax and gross of the income tax, adjusts downwards just enough to leave the producer and the consumer price of labour unchanged. As no other relative prices are affected, the equilibrium solution remains unchanged.

The result becomes understandable when noting that the payroll tax affects the union's optimal wage only through the elasticity of labour demand. The latter being constant, the net wage would not change and the burden of a payroll tax increase would be completely borne by the producers (Holmlund et al, 1989). This is in line with Holm and Koskela (1997) who find that the nominal incidence of labour tax plays no role in a monopoly union model with a single input and constant demand elasticity as long as the bases of the two taxes coincide. However, the equivalence result only holds good for a payroll tax that is uniform across sectors.

It was noted above that a cut in the labour income tax tends to destroy the positive environmental effects achieved through increased tax on the polluting output. This caveat would be overcome by targeting the labour tax cuts on non-polluting activities only. To simulate such policies we need to apply non-uniform payroll tax rates of labour across sectors. The analysis in section 3.2 showed that the effect on the environment of the payroll tax in the non-polluting sector is a priori ambiguous and depends on the substitutability of different consumption categories.

Therefore, we run a simulation where the increase in environmental output tax is accompanied by a drop in the payroll tax on labour in the non-polluting sector. The commodity tax rate on the polluting output is increased from 10 to 11 percent, similar to the simulations of the previous section. Now, however, instead of the general labour income tax, we allow the payroll tax rate in the non-polluting sector to adjust so as to leave net revenue intact. Results of the simulation are presented in table 5.4.

Table 5.4. Simulation results from a tax reform where consumption tax on the polluting output is increased and the payroll tax in the non-polluting sector is lowered so as to keep net revenue at the benchmark level. Unemployment benefits are tax exempted and price indexed. All entries except tax rates are percentage changes from the benchmark level

employment	4.2
pollution	-1.6
consumption	1.3
payroll tax rate in C	6.2

Clearly, lowering payroll tax in the non-polluting sector has a less adverse effect on the environment than lowering the overall labour income tax. Actually, as we showed in section 3.2, with high enough elasticity of substitution between the two consumption categories, lowering the payroll tax of the non-polluting sector will reduce output in the polluting sector. This is exactly what is happening in table 5.4 as pollution reduces more than in the case where the increase in environmental tax is not compensated (table 5.2).[42] In terms of non-environmental efficiency, reflected by the employment and the consumption index, the targeted rebate policy performs worse than the labour income tax reduction presented in the second column of table 5.3. This is due to the increased distortions in the commodity markets caused by the differentiated payroll tax rate. Intuitively, labour income tax is a "green" tax whereas payroll tax in the non-polluting activities is not. Both, however, are harmful to employment and consumption.

5.5 Sensitivity of the Results to Changes in Consumer Preferences

Having found with some plausible parameter values that targeted rather than general cuts in the taxation of labour are likely to produce a double dividend, we now proceed to analyse the sensitivity of these results to changes in the parameters reflecting consumer preferences. With the CES-utility function, consumer preferences are described

[42] It should be noted that with elasticity of substitution exceeding the critical level, the "environmental dividend" is guaranteed if compensation is done through payroll tax in the non-polluting sector.

by two parameters: the share parameter, δ and the elasticity parameter, γ in (2.13), respectively.

The Consumption Share Parameter

We first take a look at how the results from the revenue neutral tax reform change if the share parameter of the polluting output is increased from its original level.[43] The results of the simulations are shown in table 5.5. The results in the first column of table 5.5 indicate that as the share of polluting output in consumption grows, it becomes even less likely that a revenue neutral switch from labour income to environmental tax would lead to a double dividend. This is due to the failure of such policies to reduce the level of polluting output. The higher the share of polluting output, the larger the drop in income tax that can be afforded, which then serves to boost output in both sectors.

The case where compensation is targeted on the non-polluting sector is presented in the second column of table 5.5. The larger share of polluting output enables a larger targeted cut in the taxation of labour, leading to a stronger growth of employment. However, the positive output effect is limited to the non-polluting sector and the environment does not deteriorate.

Table 5.5. Simulation results from a revenue neutral tax reform when the consumption share parameter of polluting output is increased from the original 0.3 to 0.4. Unemployment benefits are tax exempted and price indexed. All entries except tax rates are percentage changes from the benchmark level

	labour income tax adjusts	payroll tax in C adjusts
employment	7.5	6.9
pollution	1.4	-1.6
consumption	2.4	2.2
labour tax rate	5.3	10.0
payroll tax in C	10.0	2.7

[43] For given substitution elasticity parameter, increase in the share parameter implies an increase in the consumption share of that particular commodity in the benchmark.

With both tax policies, the positive employment effect becomes stronger as the share of polluting output increases. The figures in table 5.5 indicate an unemployment rate of 3.2 per cent if labour income tax is cut. If compensation is carried out by lowering the payroll tax in the non-polluting sector, the unemployment rate will drop to 3.8 per cent.

The results of simulations where the share parameter of the polluting output is decreased from its original level are shown in table 5.6. The first column shows that in this case the increase in employment due to lower labour income tax is not sufficient to overcome the negative effect on polluting output due to higher environmental tax. Consequently, environmental quality improves together with employment and a double dividend is reached. Intuitively, with the low initial share of polluting output, the "first round" increase in the tax revenue remains small and only a moderate decrease in the labour income tax can be afforded.

The case where compensation is targeted on the non-polluting sector is presented in the second column of table 5.6. The lower share of polluting output enables a smaller targeted cut in the taxation of labour, leading to only minor growth in employment. Also the depressing effect on the polluting output is smaller, which explains why pollution drops less than in table 5.4.

Table 5.6. Simulation results from a revenue neutral tax reform when the consumption share parameter of polluting output is decreased from the original 0.3 to 0.2. Unemployment benefits are tax exempted and price indexed. All entries except tax rates are percentage changes from the benchmark level

	labour income tax adjusts	payroll tax in C adjusts
employment	2.0	1.9
pollution	-0.7	-1.5
consumption	0.6	0.6
labour tax rate	8.8	10.0
payroll tax in C	10.0	8.4

The simulation results presented in tables 5.5 and 5.6 are in line with the findings of Bayindir-Upmann & Raith (1997). Applying a model with wage bargaining they find that if the expenditure share of "dirty" consumption is large enough, a revenue neutral reform will lead to increased level of pollution. In the accompanying commentary Bayindir-Upmann and Raith note that relatively high expenditure shares of polluting output are most likely to occur in practical applications and therefore reject the possibility of a double dividend.

The Elasticity of Substitution Parameter

Next, we consider the effects of changes in the elasticity of substitution between the polluting and the non-polluting output in consumption. To isolate the pure effect of increased substitutability, the share of polluting output at the benchmark is set to the level implied by the base case. Results of a simulation where the elasticity of substitution was lowered are presented in table 5.7.

The results in table 5.7 show that lowering the substitution elasticity between the two consumption categories weakens the ability of either policy to provide a double dividend. Lower substitution elasticity leads to a smaller drop in the polluting consumption after a given increase in the environmental tax rate. This affects the level of pollution directly. In addition, the revenue from environmental tax tends to grow more, enabling a somewhat larger drop in the income tax rate and stronger growth in employment and output in comparison to the base case presented in the second column of table 5.3.

Table 5.7. Simulation results from a revenue neutral tax reform when the consumption elasticity of substitution is decreased from the original 2.0 to 0.67. Unemployment benefits are tax exempted and price indexed. All entries except tax rates are percentage changes from the benchmark level

	labour income tax adjusts	payroll tax in C adjusts
employment	4.4	4.3
pollution	1.0	0.3
consumption	1.4	1.4
labour tax rate	7.2	10.0
payroll tax in C	10.0	6.1

This is also true when compensation is awarded through the payroll tax in the non-polluting sector. As was shown in section 3.2, if the elasticity of substitution is low enough, a drop in the payroll tax of the non-polluting sector will boost output in the polluting sector. Intuitively, the sector specific payroll tax then approaches a uniform payroll tax and thus the labour income tax. However, the sector specific payroll tax will still discriminate between sectors so that the polluting output grows less than in the case where labour income tax is reduced. This is why pollution grows less in the second column of table 5.7.

Finally, we simulate a case where the elasticity of substitution between the two consumption categories is considerably increased. The results of the simulation are presented in table 5.8. The results in the first column show that with a large enough elasticity of substitution, a double dividend can be achieved even when compensations are made through labour income tax. Because of the high elasticity of substitution, increased environmental tax leads to a strong change in the consumption pattern in favour of the non-polluting good. Consequently, the drop in labour tax rate afforded within the budget constraint is not adequate to overrule the drop in polluting output. This finding challenges the result of Bayindir-Upmann and Raith (1997) referred to above: a double dividend can be achieved even with a high share of polluting output, given that substitution elasticity is high enough.[44]

[44] In other words, the "critical share" of Bayindir-Upmann and Raith (1997) depends positively the elastic-

The results for the case in which compensation is awarded through the payroll tax in the non-polluting sector are shown in the second column of table 5.8. As with an income tax compensation, increased environmental tax leads to a strong alteration in the consumption pattern in favour of the non-polluting good. In addition, the drop in payroll tax afforded is somewhat lower due to the erosion of the tax base and the lower revenue from environmental tax. Therefore, the gain in terms of employment remains smaller than in table 5.4. The environmental dividend is larger in turn.

Table 5.8. Simulation results from a revenue neutral tax reform when the consumption elasticity of substitution is increased from the original 2.0 to 4.0. All entries except tax rates are percentage changes from the benchmark level

	labour income tax adjusts	payroll tax in C adjusts
employment	4.3	4.0
pollution	-0.7	-3.5
consumption	1.4	1.3
labour tax rate	7.3	10.0
payroll tax in C	10.0	6.4

To sum up, the numerical simulations suggest that a revenue neutral switch from labour taxes to environmental taxes would improve employment. The increase in employment would in most cases be quite considerable. The magnitude of the employment effect depends positively on the share of polluting output in consumption. With the 20 per cent share assumed at the benchmark, a ten per cent increase in the environmental tax would reduce unemployment to roughly six per cent from the initial ten per cent. However, a simultaneous attainment of lower level of pollution and thus a double dividend seems less secure.

ity of substitution between polluting and non-polluting consumption. The authors do not acknowledge this qualification, since they implicitly fix substitution elasticity to unity by choosing a Cobb-Douglas specification for preferences.

With the general labour income tax cut, a double dividend can only be attained if the share of the polluting output in consumption is low. This is because the general cuts in taxation of labour tends to boost the polluting output and thus undermine the environmental goals of the reform. The likelihood of a double dividend arising is much greater if the labour tax cuts are targeted on non-polluting activities. Even then, a prerequisite for a double dividend is that the elasticity of substitution between polluting and non-polluting consumption should be sufficiently large.

6. Conclusions

This paper examines the effects of labour and environmental taxes in a general equilibrium framework allowing for imperfectly competitive labour markets and involuntary unemployment. The environmental externality is related to the consumption of a polluting output. Our modelling of labour markets consists of a centralised monopoly trade union confronting a constant elasticity labour demand by the firms employing two variable inputs, labour and capital. Institutional factors such as the financing of unemployment benefits by public revenues and their tax treatment are taken account of in the model.

With reference to the double dividend hypothesis, our specific interest is to examine whether employment and environment can be improved through an environmentally motivated restructuring of the tax system. In particular, we consider a revenue neutral switch from labour income tax to a consumption tax on a polluting output.

We assume throughout that the labour supply is inelastic.[45] Then it is the differential tax treatment of unemployment benefits that makes labour income tax harmful to employment in the model. Increased labour income tax leads to a higher wage bid by the union. As the labour income tax increases wages without discriminating between the production sectors, it does reduce output in both the polluting and the non-polluting activities thus serving as a "green" tax in ultimately reducing pollution.

The environmental tax on polluting output has a negative effect on employment and pollution irrespective of the tax treatment of unemployment benefits. Consequently, if unemployment benefits are taxed at a rate equal to labour income, a switch from labour income tax to environmental tax will unambiguously decrease employment and improve the environment.

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[45] This assumption finds support from numerous empirical studies reporting low values for wage elasticity of labour supply (see e.g. Kuismanen, 1993, 1997).

As long as unemployment benefits are exempted, the effects of a payroll tax on labour are identical to those of the labour income tax. This well known equivalence result only holds for a payroll tax uniform across sectors. We show that an increase in the sector specific payroll tax of the non-polluting sector will reduce employment and either improve or harm the environment depending on the model parameters.

With unemployment benefits exempted or taxed at a rate lower than labour income, we find that an uncompensated increase in either the labour income tax or the environmental tax leads to lower equilibrium level of employment and polluting output. Consequently, the effect on employment and environment of a "green" tax reform that preserves the real level of public expenditure is a priori ambiguous. The conditions under which a double dividend arises depend on the selection of model parameters. Our numerical simulations with plausible parameter values show that employment would improve after such a reform. The magnitude of the employment effect is relatively large. A ten percent increase in the environmental tax would cut the structural unemployment rate to roughly two thirds of its benchmark level.

However, the attainability of a double dividend is prevented by an increase in the polluting output due to the cut in the labour income tax. Thus, the positive employment effect tends to undermine the environmental goals of the reform. Achievement of an environmental dividend is less likely the higher the share of the polluting output in total consumption.

This caveat might be avoided if cuts in the taxation of labour are targeted on the payroll tax in the non-polluting activities. Even then, as our simulations show, a necessary condition for a double dividend to arise is that the elasticity of substitution between polluting and non-polluting output is sufficiently large. This finding simply reflects the fact that environmental policies through taxation can be successful only if close enough non-polluting substitutes are available.

The results are broadly in line with the findings of earlier studies on the double dividend issue. As is typical in non-clearing labour market models, we find a potentially positive employment dividend due to increased wage moderation. Qualitatively the employment effects are similar to those derived in a single input framework by Koskela & Schöb (1997). In two input models with competitive labour markets the possibility of a double dividend arises due to the tax burden being shifted from labour to relatively immobile capital (e.g. de Mooij & Bovenberg, 1998). In our setting, with unemployment benefits financed through taxes, the tax burden is not only shifted but also reduced after a reform that nonetheless leaves real public expenditure intact. This, together with a relatively large base for the environmental tax explains why the employment effects found in the model are large in comparison to the moderate effects reported in many earlier studies (e.g. OECD, 1997 and Honkatukia, 1997).

Like Bayindir-Uppman & Raith (1997) our results emphasise that the second dividend cannot be taken for granted. This is the case in particular when the share of the polluting output in consumption is large. The policy implication is that checking out employment effects is simply not enough to justify a "green" reform. The sign and possibly the magnitude of environmental effects must also be evaluated. A related topic calling for further research is the implementation of consumption based environmental taxes (see e.g. OECD, 1997). The feasibility and environmental effectiveness of such taxes is presumed in the theoretical models, but in reality large scale implementation is so far limited to fossil fuels.

The present model is in many ways simplified and can hardly be given much empirical relevance. However, we believe the model serves to clarify the mechanisms driving the effects of environmental tax reform on an economy with corporative labour markets. One of the lessons taught by the calculations is the obvious exacerbation of negative employment effects of labour taxes in models with monopoly union structure and constant labour demand elasticity. While suggesting complete after tax real wage rigidity, such models lead to dramatic changes in employment due to increased labour tax rates. A possibly more realistic model would allow labour demand elasticity to vary according to the tightness of the labour market thereby producing a more moderate wage response. Another aspect favouring wage moderation would be to allow for at least a partial perception of the tax benefit link on the part of the labour union (see e.g. Summers, 1993, Alesina and Perotti, 1997). In that case the wage response would be mitigated to the degree that the centralised wage bargaining would accept improved public benefits as partial compensation for increased taxes.

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Appendix 1: Derivation of Firms' Input Demand

The production block of the model consists of two sectors, each incorporating a large number of competitive firms. The firms employ an unitary elasticity of substitution technology with two inputs, labor and capital, and diminishing returns to scale. The production function of a single firm in sector i is presented by

$$f_i(L_i, K_i) = \Omega_i L_i^{\alpha_i} K_i^{\beta_i} \qquad \text{(A1.1)}$$

The problem of a profit maximizing firm is to choose an input bundle so as to maximize the profits given by (2.1)

$$\Pi_i = q_i \Omega_i L_i^{\alpha_i} K_i^{\beta_i} - q_{Li} L_i - q_k K_i$$

The first order conditions of the problem are

$$q_i f_{iL} - q_{Li} = q_i f_{iK} - q_K = 0 \qquad \text{(A1.2)}$$

where $f_{ij} = \partial f_i / \partial j, j = K, L$ are partial derivatives of the production function with respect to the inputs. Developing (A1.2) further, we get

$$\alpha_i q_i \Omega_i L_i^{\alpha_i - 1} K_i^{\beta_i} - q_{Li} = 0$$
$$\beta_i q_i \Omega_i L_i^{\alpha_i} K_i^{\beta_i - 1} - q_K = 0 \qquad \text{(A1.4)}$$

Solving for L_i and K_i respectively and substituting yields the optimal input demands in terms of the producer prices given by (2.2)

$$L_i = \Omega_{Li} \left[q_i q_k^{-\beta_i} q_{Li}^{-(1-\beta_i)} \right]^{1/\Delta_i}$$
$$K_i = \Omega_{Ki} \left[q_i q_k^{-(1-\alpha_i)} q_{Li}^{-\alpha_i} \right]^{1/\Delta_i}$$

where $\Delta_i = 1 - \alpha_i - \beta_i$, $\Omega_{Li} = \left(\Omega_i \alpha_i^{1-\beta_i} \beta_i^{\beta_i}\right)^{1/\Delta_i}$ and $\Omega_{Ki} = \left(\Omega_i \alpha_i^{\alpha_i} \beta_i^{1-\alpha_i}\right)^{1/\Delta_i}$. Since we assume identical firms within sectors, sectoral input demands can be found by multiplying the firm level demands by the number of firms in each sector.

Appendix 2: Derivation of Consumer Demand and CPI

Consumer demand

In the model we have three types of consumers that differ in their position at the labor markets. All consumers are either employed in one of the two production sectors or unemployed. All consumers supply one unit of labor and have identical utility defined over consumption and environmental quality as presented in (2.13)

$$U_j = v(C_j, D_j) + u(E), \gamma \leq 1, u' > 0$$
$$v = \left[\delta C_j^{\gamma} + (1-\delta)D_j^{\gamma}\right]^{1/\gamma} \qquad \text{(A2.1)}$$

where the subscript j=c,d,u refer to the three types of consumers classified according to their position at the labor market. Thus, C_d is the quantity of non-polluting good consumed by an individual being employed in the sector producing the polluting good and so forth. Function u is a separable subutility function on environmental quality, E.

The problem of an individual consumer is to choose a consumption bundle so as to maximize (A2.1) subject to their budget constraint defined by (2.11) or (2.12) depending on the employment status. As usual, we assume that a single consumer can ignore the effect of their consumption on the environmental quality. The first order conditions of the optimizing problem are

$$\partial U_j/\partial C_j - \lambda_j p_c = \partial U_j/\partial D_j - \lambda_j p_d = 0 \qquad \text{(A2.2)}$$

where λ_j is the Lagrange multiplier reflecting the marginal utility of income for consumer of type j. Developing (A2.2) further yields

$$\delta C_j^{\gamma-1}\left[\delta C_j^{\gamma}+(1-\delta)D_j^{\gamma}\right]^{1/\gamma-1}-\lambda_{ik}p_c=0$$
$$(1-\delta)D_j^{\gamma-1}\left[\delta C_j^{\gamma}+(1-\delta)D_j^{\gamma}\right]^{1/\gamma-1}-\lambda_j p_d=0 \qquad \text{(A2.3)}$$

Eliminating λ_j gives

$$C_j/D_j=\left[\frac{\delta p_d}{(1-\delta)p_c}\right]^{1/(1-\gamma)}$$

which is (2.14). Substituting (2.14) for C_j in the individual budget constraint defined by (2.11) or (2.12) gives

$$p_c\left[\frac{\delta p_d}{(1-\delta)p_c}\right]^{\sigma}D_j+p_dD_j=m_j \qquad \text{(A2.3)}$$

where m_j is the individual income taken as given by the consumer and $\sigma=1/(1-\gamma)$ is the elasticity of substitution between the two consumption goods. Dividing through by p_dD_j and rearranging then yields

$$D_jp_d\left[\frac{\delta^{\sigma}p_c^{1-\sigma}+(1-\delta)^{\sigma}p_d^{1-\sigma}}{(1-\delta)^{\sigma}p_d^{1-\sigma}}\right]=m_j \qquad \text{(A2.4)}$$

Repeating similar treatment for C_j yields

$$C_jp_c\left[\frac{\delta^{\sigma}p_c^{1-\sigma}+(1-\delta)^{\sigma}p_d^{1-\sigma}}{\delta^{\sigma}p_c^{1-\sigma}}\right]=m_j \qquad \text{(A2.5)}$$

Consumer price index

To define a measure for the price of the aggregate consumption that allows for substitution between goods, we write

$$p_cC_j+p_dD_j=pv \qquad \text{(A2.6)}$$

where v is the subutility function on the two outputs defined in (A2.1) and p refers to cost per unit of that utility. Then noting that (A2.3) can be rewritten as

$$C_j = [\delta^{-1}\lambda_j p_c]^{-\sigma} v$$
$$D_j = \left[(1-\delta)^{-1}\lambda_j p_d\right]^{-\sigma} v \qquad \text{(A2.7)}$$

which gives the compensated demands for the two outputs, respectively. We then substitute (A2.7) into (A2.1) to get

$$\lambda_j^{-\sigma} = \left[\delta^{\sigma} p_c^{1-\sigma} + (1-\delta)^{\sigma} p_d^{1-\sigma}\right]^{1/(1-\sigma)} \qquad \text{(A2.8)}$$

Substituting (A2.7) and (A2.8) into (A2.6) then yields

$$p = \left[\delta^{\sigma} p_c^{1-\sigma} + (1-\delta)^{\sigma} p_d^{1-\sigma}\right]^{1/(1-\sigma)} \qquad \text{(A2.9)}$$

which is (2.16). Substituting (A2.9) into (A2.4) and (A2.5) then yields (2.15).

Appendix 3: Equilibrium Solution

The goods market equilibrium is characterized by the two equations given by (2.27)

$$1-\delta^{\sigma}(1+t_c)^{-\sigma}(1+s_c)^{\alpha/\Delta}q_c^{-(\Delta\sigma+\alpha+\beta)/\Delta}I_1I_2=0$$
$$1-(1-\delta)^{\sigma}(1+t_d)^{-\sigma}(1+s_d)^{\alpha/\Delta}q_d^{-(\Delta\sigma+\alpha+\beta)/\Delta}I_1I_2=0$$

To solve the set of equations (2.27) we set the left hand sides of the two equations equal and eliminate I_1 and I_2 to get

$$\frac{q_d}{q_c}=\left[\left(\frac{1-\delta}{\delta}\frac{1+t_c}{1+t_d}\right)^{\sigma}\left(\frac{1+s_c}{1+s_d}\right)^{\alpha/\Delta}\right]^{\Delta/(\Delta\sigma+\alpha+\beta)}\equiv\left[\left(\frac{1-\delta}{\delta}\frac{1+t_c}{1+t_d}\right)^{\sigma}\left(\frac{1+s_d}{1+s_c}\right)^{\alpha/\Delta}\right]^{\Delta\sigma/(\Delta\sigma+1-\Delta)} \quad \text{(A3.1)}$$

which is (2.28) rewritten using the definition $\Delta\equiv 1-\alpha-\beta$. I_1 and I_2 are as defined in (2.23)

$$I_1=\left[(1+t_c)(1+s_c)^{-\alpha/\Delta}q_c^{1/\Delta}+(1+t_d)(1+s_d)^{-\alpha/\Delta}q_d^{1/\Delta}\right]$$
$$I_2=\left[\delta^{\sigma}(1+t_c)^{1-\sigma}q_c^{1-\sigma}+(1-\delta)^{\sigma}(1+t_d)^{1-\sigma}q_d^{1-\sigma}\right]^{-1}$$

which we rewrite as

$$I_1=q_c^{1/\Delta}(1+s_c)^{-\alpha/\Delta}\left[(1+t_c)+(1+t_d)\left(\frac{1+s_d}{1+s_c}\right)^{-\alpha/\Delta}\left(\frac{q_d}{q_c}\right)^{1/\Delta}\right]$$
$$I_2=q_c^{\sigma-1}\delta^{-\sigma}(1+t_c)^{\sigma}\left[(1+t_c)+(1+t_d)\left(\frac{1-\delta}{\delta}\frac{1+t_c}{1+t_d}\right)^{\sigma}\left(\frac{q_d}{q_c}\right)^{1-\sigma}\right]^{-1} \quad \text{(A3.2)}$$

Then substituting (A3.1) for (q_d/q_c) in the first equation of (A3.2) gives

$$I_1 = q_c^{1/\Delta}(1+s_c)^{-\alpha/\Delta}\left[(1+t_c)+(1+t_d)\left(\frac{1+s_d}{1+s_c}\right)^{-\alpha/\Delta}\left[\left(\frac{1-\delta}{\delta}\frac{1+t_c}{1+t_d}\right)^{\sigma}\left(\frac{1+s_d}{1+s_c}\right)^{\alpha/\Delta}\right]^{1/(\Delta\sigma+\alpha+\beta)}\right]$$

$$= q_c^{1/\Delta}(1+s_c)^{-\alpha/\Delta}\left[(1+t_c)+(1+t_d)\left(\frac{1-\delta}{\delta}\frac{1+t_c}{1+t_d}\right)^{\sigma}\left[\left(\frac{1-\delta}{\delta}\frac{1+t_c}{1+t_d}\right)^{\sigma}\left(\frac{1+s_d}{1+s_c}\right)^{\alpha/\Delta}\right]^{\frac{\Delta(1-\sigma)}{\Delta\sigma+\alpha+\beta}}\right]$$

$$= q_c^{1/\Delta}(1+s_c)^{-\alpha/\Delta}\delta^{-\sigma}(1+t_c)^{\sigma}q_c^{\sigma-1}I_2^{-1} \quad \text{(A3.3)}$$

Noting that $q_c^{1/\Delta}q_c^{\sigma-1} = q_c^{(\Delta\sigma+\alpha+\beta)/\Delta}$ and substituting (A3.3) back to (2.27), it is easy to see that the first equation holds as an identity. Thus, the two equations in (2.27) must be dependent and either one can be dropped. Consequently, we can only solve for the relative price of the two outputs.

Appendix 4: Second Order Necessary Conditions for the Union's Optimum

To prove that the stationary point chosen by the union in section 2.5 is indeed a maximum, we show that the sign of the second derivative of the union's objective is negative (see e.g. Chiang, 1984). Recalling the union's objective (2.45') and differentiating yields the first derivative

$$dV/dw = (dL/dw)[(1-t_L)wp^{-1}-b]+L(1-t_L)p^{-1}[1-wp^{-1}(dp/dw)] \qquad \text{(A4.1)}$$

By (2.37) $dp/dw = 0$, and (A4.1) can be simplified to

$$dV/dw = (dL/dw)[(1-t_L)wp^{-1}-b]+L(1-t_L)p^{-1} \qquad \text{(A4.2)}$$

Differentiating (A4.2) with respect to wage rate yields the second derivative of union's objective

$$d^2V/dw^2 = 2(1-t_L)p^{-1}(dL/dw)+[(1-t_L)wp^{-1}-b](d^2L/dw^2) \qquad \text{(A4.3)}$$

To show that (A4.3) is indeed negative, we recall (2.43) to get

$$dL/dw = -(1-\alpha)^{-1}w^{-1}L \qquad \text{(A4.4)}$$

Differentiating (A4.4) yields

$$d^2L/dw^2 = (1-\alpha)^{-1}\left[\tfrac{dL}{dw}w^{-1}-w^{-2}L\right] \qquad \text{(A4.5)}$$

which is the second derivative of aggregate labor demand with respect to the net wage defined in terms of the non-polluting output. Substituting (A4.4) into (A4.5) gives

$$d^2L/dw^2 = (1-\alpha)^{-1}(2-\alpha)w^{-2}L > 0 \qquad \text{(A4.5')}$$

Further substituting (A4.4) and (A4.5') into (A4.3) gives

$$\begin{aligned} d^2V/dw^2 &= -2(1-\alpha)^{-1}(1-t_L)p^{-1}w^{-1}L + \tfrac{(2-\alpha)}{(1-\alpha)}[(1-t_L)wp^{-1} - b]w^{-2}L \\ &= (1-\alpha)^{-1}w^{-1}L\left[-2(1-t_L)p^{-1} + \tfrac{(2-\alpha)}{(1-\alpha)}(1-t_L)p^{-1} - \tfrac{(2-\alpha)}{(1-\alpha)}bw^{-1}\right] \qquad \text{(A4.3')} \end{aligned}$$

The terms outside the square brackets in (A4.3') are invariably positive. Denoting the formula within the square brackets by Θ and substituting the wage equation (2.50) for the net wage, w, we get

$$\begin{aligned} \Theta &\equiv -2(1-t_L)p^{-1} + \tfrac{(2-\alpha)}{(1-\alpha)}(1-t_L)p^{-1} - \tfrac{(2-\alpha)}{(1-\alpha)}\alpha(1-t_L)p^{-1} \\ &= \tfrac{(2-\alpha)}{(1-\alpha)}(1-t_L)p^{-1}\left[-\tfrac{2(1-\alpha)}{(2-\alpha)} + 1 - \alpha\right] \\ &= -\tfrac{(2-\alpha)}{(1-\alpha)}(1-t_L)p^{-1}\left[\tfrac{\alpha(1-\alpha)}{(2-\alpha)}\right] < 0 \qquad \text{(A4.6)} \end{aligned}$$

Thus by (A4.3') and (A4.6) the second derivative of the union's objective is negative at the stationary point which thus represent a (global) maximum.[1]

[1] Since the first derivative in (A4.2) has a single stationary point, the condition needed for the maximum to be global is that the first derivative in (A4.2) is well defined for all positive wage rates.

Appendix 5: Derivation of the Effect of Environmental Tax on CPI and Wages

In section 3.1 we noted that the environmental tax has two opposite effects on the wage rate and thus the sign of the total effect is a priori ambiguos. Due to the constancy of the labor demand elasticity, the effect of the environmental tax on wages comes solely through changes in general price level measured by the CPI (see the wage equation 2.50'). Therefore, to determine the effect of the environmental tax on wages we need to find the effect of the tax on CPI. In what follows we show that the environmental tax indeed increases both the CPI and the wages.

First, we recall the union's optimal wage equation (2.50'). With a uniform payroll tax across sectors we may define the producer price of labor as

$$q_L = \frac{(1+s)bp}{\alpha(1-t_L)}$$

Differentiating with respect to the environmental tax then yields

$$\frac{dq_L}{d(1+t_d)} = \Upsilon_1 \frac{dp}{d(1+t_d)} \qquad \text{(A5.1)}$$

where

$$\Upsilon_1 \equiv \frac{(1+s)b}{\alpha(1-t_L)} > 0$$

is a positive constant. Thus by (A5.1)

$$sign\left(\frac{dq_L}{d(1+t_d)}\right) = sign\left(\frac{dp}{d(1+t_d)}\right) \qquad \text{(A5.2)}$$

in other words, the effect of the environmental tax on wages is of the same sign as its effect on the CPI. To derive the effect of environmental tax on CPI we recall equation (2.36) defining CPI in terms of the tax rates and the relative price of the two outputs.

$$p = \left[\delta^{\sigma}(1+t_c)^{1-\sigma} + (1-\delta)^{\sigma}(1+t_d)^{1-\sigma} q_d{}^{1-\sigma}\right]^{1/(1-\sigma)}$$

Substituting (2.28') for the relative price of the two outputs yields

$$\begin{aligned} p &= \left[\delta^{\sigma}(1+t_c)^{1-\sigma} + (1-\delta)^{\sigma}(1+t_d)^{1-\sigma}\left[\tfrac{1-\delta}{\delta}\tfrac{1+t_c}{1+t_d}\right]^{\Delta\sigma(1-\sigma)/(\Delta\sigma+\alpha+\beta)}\right]^{1/(1-\sigma)} \\ &= \left[\Upsilon_2 + \Upsilon_3(1+t_d)^{(1-\sigma)(\alpha+\beta)/(\Delta\sigma+\alpha+\beta)}\right]^{1/(1-\sigma)} \end{aligned} \qquad \text{(A5.3)}$$

where

$$\Upsilon_2 \equiv \delta^{\sigma}(1+t_c)^{1-\sigma} > 0$$

$$\Upsilon_3 \equiv (1-\delta)^{\sigma}\left[\tfrac{1-\delta}{\delta}(1+t_c)\right]^{\Delta\sigma(1-\sigma)/(\Delta\sigma+\alpha+\beta)} > 0$$

are strictly positive constants. Thus, equation (A5.3) expresses CPI as a function of the exogenous model parameters and the tax rates. Differentiating (A5.3) with respect to the environmental tax yields

$$\frac{dp}{d(1+t_d)} = \frac{\alpha+\beta}{\Delta\sigma+\alpha+\beta}\Upsilon_3\left[\Upsilon_2 + \Upsilon_3(1+t_d)^{\frac{(1-\sigma)(\alpha+\beta)}{(\Delta\sigma+\alpha+\beta)}}\right]^{1/(1-\sigma)-1}(1+t_d)^{\frac{(1-\sigma)(\alpha+\beta)}{(\Delta\sigma+\alpha+\beta)}-1} > 0 \qquad \text{(A5.4)}$$

in other words, an increase in the environmental tax increases the consumer price index. The direct effect of an increased tax rate dominates the indirect effect through a lower output price. Consequently, by (A5.2)

$$\frac{dq_L}{d(1+t_d)} > 0 \qquad \text{(A5.5)}$$

in other words, an increase in the environmental tax increases the producer price of labor. Result (A5.5) is in line with that derived by Koskela & Schöb (1997).[2]

[2] Koskela & Schöb (1997) show in a partial equilibrium framework that an increase in the environmental tax leads to a higher wage bid by the union if unemployment benefits are price indexed.

Appendix 6: Derivation of the Double Dividend Conditions

The change in employment after a simultaneous change in the two tax rates is given by (4.7)

$$dL = [L_{ql}q_{LL}]d(1 - t_L) + [L_{ql}q_{LD} + L_{qd}q_{DD}]d(1 + t_d)$$

The change in the labor income tax required to keep the revenue unchanged after an increase in the environmental tax is found from (4.10)

$$d(1 - t_L) = \frac{\hat{T}_{td}}{\hat{T}_{tl}} d(1 + t_d)$$

Substituting (4.10) for $d(1 - t_L)$ in (4.7) yields

$$dL = \left[\left(\frac{\hat{T}_{td}}{\hat{T}_{tl}}\right) L_{ql}q_{LL} + L_{ql}q_{LD} + L_{qd}q_{DD}\right] d(1 + t_d) \qquad \text{(A6.1)}$$

which defines the change in employment after a revenue neutral switch in the tax structure in favour of the environmental tax when $d(1 + t_d) > 0$. Setting (A6.1) greater than zero yields the condition for improved employment

$$\frac{\hat{T}_{td}}{\hat{T}_{tl}} > \frac{-\left(L_{ql}q_{LD} + L_{qd}q_{DD}\right)}{L_{ql}q_{LL}} \qquad \text{(A6.2)}$$

Multiplying (A6.2) through by $-\hat{T}_{tl}/(L_{ql}q_{LD} + L_{qd}q_{DD}) > 0$ yields the condition (4.11). To present (A6.2) in terms of elasticities, we rewrite it as

$$\frac{\hat{T}_{td}}{\hat{T}_{tl}} > -\frac{q_{LD}}{q_{LL}} - \frac{L_{qd}q_{DD}}{L_{ql}q_{LL}} \qquad \text{(A6.2')}$$

Then multiplying through by $t_d/t_L > 0$ and some manipulation gives (4.11')

$$\frac{\hat{\tau}_{td}}{\hat{\tau}_{tl}} > \frac{\omega_{td}}{\omega_{tl}} + \frac{\varepsilon_{qd}\eta_{td}}{\varepsilon_{ql}\omega_{tl}}$$

where

$$\hat{\tau}_{td} \equiv \frac{\partial \hat{T}}{\partial t_d}\frac{t_d}{\hat{T}}$$

$$\hat{\tau}_{tl} \equiv \frac{\partial \hat{T}}{\partial t_l}\frac{t_l}{\hat{T}}$$

are the elasticities of the net revenue with respect to the tax rates, and

$$\omega_{td} \equiv \frac{dq_L}{dt_d}\frac{t_d}{q_L}$$

$$\omega_{td} \equiv \frac{dq_L}{dt_l}\frac{t_l}{q_L}$$

are the elasticities of the producer price of labor with respect to the tax rates, and

$$\varepsilon_{qd} \equiv \frac{\partial L}{\partial q_d}\frac{q_d}{L}$$

$$\varepsilon_{ql} \equiv \frac{\partial L}{\partial q_l}\frac{q_l}{L}$$

are the elasticities of employment with respect to producer prices of output and labor, and finally

$$\eta_{td} \equiv \frac{dq_d}{dt_d}\frac{t_d}{q_d}$$

is the elasticity of the output price with respect to the environmental tax. Substitution of the revenue neutrality condition (4.10) into the formula of the polluting output (4.8) and applying similar procedure yields the conditions (4.12) and (4.12') for improvement in environmental quality.

Appendix 7: Taxed Unemployment Benefits

In section 2.5 we derived the optimal wage rate for a monopoly union given that unemployment benefits are exempted from tax. In this appendix we derive the optimal wage rate in the more general case where unemployment benefits are taxed at some non-negative rate. Recalling the objective of the union defined in (2.44) we have

$$V = Lp_L/p + (M-L)b_n/p$$

where M is the number of union members, L is the number of employed members, p_L is the after tax net wage or consumer price of labor, p is the consumer price index and b_n is the after tax unemployment benefit. Assuming that unemployment benefit is price indexed and taxed with rate t_b, we can write

$$b_n = (1-t_b)bp \tag{A7.1}$$

where b is the real unemployment benefit. Then the union objective may be rewritten as

$$V = L(1-t_L)q_L/p + (M-L)(1-t_b)b. \tag{A7.2}$$

Rearranging gives

$$V = L(1-t_L)\left[wp^{-1} - \tfrac{(1-t_b)}{(1-t_L)}b\right] + M(1-t_b)b \tag{A7.3}$$

The problem of the union is to set the wage rate so as to maximize (A7.3). The first order condition for optimal wage rate now becomes

$$(1-t_L)\left\{(dL/dw)\left[wp^{-1}-\tfrac{(1-t_b)}{(1-t_L)}b\right]+L[p^{-1}-wp^{-2}(dp/dw)]\right\}=0 \qquad \text{(A7.4)}$$

where we have utilized the fact that the second term on the right hand side of (A6.3) is taken as given by the union. Multiplying both sides by wL^{-1} and solving for the wage rate gives the optimal wage equation

$$w=\tfrac{(1-t_b)}{(1-t_L)}bp\left(1-\tfrac{1-\vartheta}{\varepsilon}\right)^{-1} \qquad \text{(A7.5)}$$

where $\varepsilon \equiv -dL/dw(w/L)>0$ is the wage elasticity of labor demand and $\vartheta \equiv dp/dw(w/p)\geq 0$ is the elasticity of consumer price index with respect to the wage rate, as before. Thus, (A7.5) provides the wage equation of the model in the case where unemployment benefits are taxed at rate t_b. The special case where benefits are taxed at rate equal to labor income is

$$w=bp\left(1-\tfrac{1-\vartheta}{\varepsilon}\right)^{-1}$$

and the case where benefits are exempted is

$$w=(1-t_L)^{-1}bp\left(1-\tfrac{1-\vartheta}{\varepsilon}\right)^{-1}$$

which is equal to (2.50).

Appendix 8: Tax Policy Evaluation with CGE Models

Computable or applied general equilibrium modeling (CGE hereafter) has its origins in the work of Harberger (1962) and Johansen (1960) that aimed to determine and quantify the general equilibrium effects of policy reforms. The early seventies saw the development of computational algorithms by Scarf (1973) and subsequent refinements by many others, but it was not before the boom of personal computers in the eighties that made CGE modeling a widespread tool for economic analysis. A comprehensive text on the CGE-method and its application to policy analysis is provided by Shoven and Whalley (1993).

The structure of a CGE-model can loosely be described by a set of equations

$$F(V) = 0 \tag{A8.1}$$

where F is a vector of functions of length m and V is a vector of variables of lenght n, n>m. In the standard models functions in F include excess demand functions for outputs and inputs derived from the constrained optimising problems of consumers and producers. To solve the model, (n-m) variables must be given an exogenous value. The normal procedure is to let the input and output prices be endogenous. Since (A8.1) satisfies the Walras law, it contains only (m-1) independent equations. Therefore, a price normalisation is usually adopted.[3]

It can be shown with the help of some rigorous mathematics based on the fixed-point theorem that solution for (A8.1) exists. The result extends with some complications to the case where taxes and transfers are included (see e.g. Showen & Whalley,1993). Finding the solution of (A8.1) is based on algorithms that are

[3] Growing interest in the unemployment problem has led to CGE-models incorporating non-clearing labor markets (e.g. de Melo and Tarr, 1993). Then the labor market clearing condition in (A8.1) is replaced by a wage equation.

variants of the Newton method for solving non-linear equation systems. In practise, the modeling work is done with computer packages involving build-in solvers.

Like their analytical counter parts, CGE-models explicitly recognize that policy changes have repercussions throughout the economy that have to be accounted for when the economic impact is evaluated. Furthermore, by their very nature, CGE-models are capable for analysing the effects of non-marginal changes in policy parameters and to produce both qualitative and quantitative results. It is this feature that makes CGE-models so attractive for policy makers. By parametrising the model to replicate real economic data, a powerfull tool for empirical policy analysis can be constructed. Usually, the parameter values are determined through a nonstochastic calibration procedure, where parameters are chosen to fit the benchmark data. Less frequently, econometric estimation with much larger data and computational requirements are used (see Mansur & Whalley 1984 for a discussion).

The major application field of CGE-models is trade policy and tax policy analysis. Surveys of the early empirical models are provided by Shoven & Whalley (1984) and Pereira & Shoven (1988). Recently, a number of applications with particular emphasis on environmental taxation has emerged (e.g. Carraro et al, 1996 and Bovenberg & Goulder, 1997.)

Appendix 9: GAMS Programm Code of the Model

```
* UEMOD1: A Computable general equilibrium model with two primary inputs and two production sectors
with decreasing returns Cobb-Douglas technology. Labour markets are non-clearing due to a "centralised"
monopoly union setting the wage rate. Government collects taxes to finance ue-benefits.
* Modelled by Pekka Sinko.Update 19.1.98

$OFFSYMLIST OFFSYMXREF
OPTION LIMROW=0;
OPTION LIMCOL=0;
OPTION SOLPRINT=OFF;

* Definition of sets
SET
  I    ENTRIES /C,D,L,K/
  J(I) NON-LABOR ENTRIES/C,D,K/
  F(I) INPUTS /L,K/
  G(J) OUTPUTS /C,D/;

ALIAS (F,FF)
   (G,GG);

* Definition of exogenous parameters
PARAMETER

     GAMMA     CES ELASTICITY PARAMETER IN CONSUMPTION
     SIGMAC    ELASTICITY OF SUBSTITUTION IN CONSUMPTION
     DELTA(G)  SHARE PARAMETER IN UTILITY
     LAMDA     SCALE PARAMETER IN UTILITY
     OMEGA(G)  C-D EFFICIENCY PARAMETER
     OMEGA2(F,G) DERIVED TECHNOLOGY PARAMETER
     BDELTA(G) DERIVED TECHNOLOGY PARAMETER

     TS(G)     PAYROLL TAX RATE BY SECTOR
     TS0(G)    BENCHMARK PAYROLL TAX RATE
     TX(G)     COMMODITY TAX RATE
     TX0(G)    BENCHMARK COMMODITY TAX RATE
     TI(F)     INCOME TAX RATE BY FACTOR
     TL0       BENCHMARK TAX RATE ON LABOR INCOME
     B0        BENCHMARK UNEMPLOYMENT BENEFITS
     TNET0     BENCHMARK NET REVENUE
```

```
    END(F)   INPUT ENDOWMENT
    M        EXOGENOUS LABOR FORCE
    TREA0    BENCHMARK REAL REVENUE
    CPB      BENCHMARK CONSUMER PRICE;

* Set values for preference & technology  parameters
TABLE ALFA(F,G)  C-D SHARE PARAMETER OF FACTOR F IN SECTOR S

          C        D
    L   0.33     0.33
    K   0.57     0.57;
GAMMA=0.75;
SIGMAC=1/(1-GAMMA);
DELTA("D")=0.3;
DELTA("C")=1-DELTA("D");
LAMDA=1;
OMEGA(G)=3.5;
BDELTA(G)=1-SUM(F,ALFA(F,G));

* Set values for computational parameters
OMEGA2("L",G)=(OMEGA(G)*ALFA("L",G)**(1-ALFA("K",G))*ALFA("K",G)**ALFA("K",G))
                  **(1/BDELTA(G));
OMEGA2("K",G)=(OMEGA(G)*ALFA("K",G)**(1-ALFA("L",G))*ALFA("L",G)**ALFA("L",G))
                  **(1/BDELTA(G));

* Set values for endowments of primary inputs
END("K")=100;
END("L")=100;

* Set values for tax rates
TX0(G)=0.1;
TX(G)=TX0(G);
TL0=0.1;
TI("L")=TL0;
TI("K")=0.1;
TS0(G)=0.1;
TS(G)=TS0(G);

* Definiotion of endogenous variables
POSITIVE VARIABLES
```

```
    D(G)    DEMAND FOR GOODS BY CONSUMERS
    X(G)    SUPPLY OF GOODS BY SECTOR
    FD(F,G) FACTOR DEMAND BY SECTOR
    UR      UNEMPLOYMENT RATE
    P(I)    CONSUMER PRICE OF I
    Q(J)    PRODUCER PRICE OF N
    QL(G)   PRODUCER PRICE LABOR OF BY SECTOR
    W       NET WAGE
    PHI(G)  PROFIT  BY SECTOR
    CPI     CONSUMER PRICE INDEX
    T       TAX REVENUE
    TIM(F)  INCOME TAX MULTIPLIER
    TSM(G)  PAYROLL TAX MULTIPLIER
    B       TOTAL UNEMPLOYMENT BENEFITS
    TREA    REVENUE IN REAL TERMS
    WRES    REAL PER UNIT UNEMPLOYMENT BENEFIT;

FREE VARIABLES

    TNET    REVENUE NET OF UNEMPLOYMENT BENEFITS IN REAL TERMS
    U       UTILITY;

* Definition of model equations
EQUATIONS

    UTIL
    BUDGET
    DEMAND
    OUTPUT
    LDEM
    KDEM
    PROF
    WAGEQ
    PIND
    KMARKET
*    CMARKET
    DMARKET
    XPRICE
    KPRICE
    LPRICE1
    LPRICE2
```

```
    GBUD
    UNEMP
    UEBEN
    REALREV
    NETREV;


UTIL..      U=E=LAMDA*((SUM(G,DELTA(G)*D(G)**GAMMA))**(1/GAMMA));
BUDGET..    SUM(G,P(G)*D(G))=E=SUM(F,P(F)*SUM(G,FD(F,G)))+SUM(G,PHI(G))+T;
DEMAND..    D("C")=E=D("D")*(DELTA("C")/DELTA("D")*P("D")/P("C"))
                   **(1/(1-GAMMA));
OUTPUT(G).. X(G)=E=OMEGA(G)*PROD(F,FD(F,G)**ALFA(F,G));
LDEM(G)..   FD("L",G)=E=OMEGA2("L",G)*(Q(G)*Q("K")**(-ALFA("K",G))*QL(G)
                   **(ALFA("K",G)-1))**(1/BDELTA(G));
KDEM(G)..   FD("K",G)=E=OMEGA2("K",G)*(Q(G)*QL(G)**(-ALFA("L",G))*Q("K")
                   **(ALFA("L",G)-1))**(1/BDELTA(G));
PROF(G)..   PHI(G)=E=Q(G)*X(G)-Q("K")*FD("K",G)-QL(G)*FD("L",G);
WAGEQ..       W=E=CPI*WRES/(ALFA("L","C")*(1-TIM("L")*TI("L")));
PIND..      CPI=E=SUM(G,DELTA(G)**SIGMAC*P(G)**(-SIGMAC*GAMMA))
                 **(-1/(SIGMAC*GAMMA));
GBUD..      T=E=SUM(G,TX(G)*Q(G)*X(G))
              +SUM(G,(TIM("L")*TI("L")+TSM(G)*TS(G))*W*FD("L",G))
              +SUM(G,TIM("K")*TI("K")*Q("K")*FD("K",G));
XPRICE(G).. P(G)=E=Q(G)*(1+TX(G));
KPRICE..    P("K")=E=(1-TIM("K")*TI("K"))*Q("K");
LPRICE1..   P("L")=E=(1-TIM("L")*TI("L"))*W;
LPRICE2(G).. QL(G)=E=(1+TSM(G)*TS(G))*W;
KMARKET..   SUM(G,FD("K",G))=E=END("K");
DMARKET..   X("D")=E=D("D");
*CMARKET..  X("C")=E=D("C");
UNEMP..     UR=E=1-SUM(G,FD("L",G))/M;
UEBEN..     B=E=WRES*CPI*(M-SUM(G,FD("L",G)));
REALREV..   TREA=E=T/CPI;
NETREV..    TNET=E=(T-B)/CPI;

MODEL ECONOMY /ALL/;

* Set initial values for endogenous variables
D.L("C")=100;
D.L("D")=60;
X.L(G)=D.L(G);
```

```
U.L=1;
FD.L("L","C")=50;
FD.L("L","D")=40;
FD.L("K","C")=60;
FD.L("K","D")=40;
Q.L("K")=1;
W.L=1;
Q.L(G)=1;
TIM.L(F)=1;
TSM.L(G)=1;
QL.L(G)=W.L*(1+TSM.L(G)*TS(G));
P.L(G)=Q.L(G)*(1+TX(G));
P.L("K")=Q.L("K")*(1-TIM.L("K")*TI("K"));
P.L("L")=W.L*(1-TIM.L("L")*TI("L"));
CPI.L=SUM(G,DELTA(G)**SIGMAC*P.L(G)**(-SIGMAC*GAMMA))**(-1/(SIGMAC*GAMMA));
T.L=SUM(G,TX(G)*Q.L(G)*X.L(G))
    +SUM(G,(TIM.L("L")*TI("L")+TSM.L(G)*TS(G))*W.L*FD.L("L",G))
    +SUM(G,TIM.L("K")*TI("K")*Q.L("K")*FD.L("K",G));
TREA.L=T.L/CPI.L;
PHI.L(G)=Q.L(G)*X.L(G)-Q.L("K")*FD.L("K",G)-QL.L(G)*FD.L("L",G);
M=END("L");
UR.L=1-(SUM(G,FD.L("L",G)))/M;
WRES.L=ALFA("L","C")*W.L*(1-TIM.L("L")*TI("L"))/CPI.L;
B.L=WRES.L*(M-(SUM(G,FD.L("L",G))))*CPI.L;
TNET.L=(T.L-B.L)/CPI.L;
CPB=SUM(G,DELTA(G)**SIGMAC*P.L(G)**(-SIGMAC*GAMMA))
     **(-1/(SIGMAC*GAMMA));

* Numeraire
Q.FX("C")=Q.L("C");

* Define report parameters
* Benchmark values of endogenous variables
PARAMETER
      D0(G)    BENCHMARK DEMAND FOR GOODS BY CONSUMERS
      X0(G)    BENCHMARK SUPPLY OF GOODS BY SECTOR
      FD0(F,G) BENCHMARK FACTOR DEMAND BY SECTOR
      UR0      BENCHMARK UNEMPLOYMENT RATE
      P0(I)    BENCHMARK CONSUMER PRICE OF I
      Q0(J)    BENCHMARK PRODUCER PRICE OF N
      QL0(G)   BENCHMARK PRODUCER PRICE LABOR OF BY SECTOR
```

W0 BENCHMARK NET WAGE
PHI0(G) BENCHMARK PROFIT BY SECTOR
CPI0 BENCHMARK CONSUMER PRICE INDEX
T0 BENCHMARK TAX REVENUE
B0 BENCHMARK TOTAL UNEMPLOYMENT BENEFITS
WRES0 BENCHMARK REAL PER UNIT UNEMPLOYMENT BENEFIT
WNET0 BENCHMARK AFTER TAX REAL WAGE
U0 BENCHMARK UTILITY;

* Other report parameters
PARAMETER
D1(G) CHANGE IN DEMAND FOR GOODS
X1(G) CHANGE IN SUPPLY OF GOODS BY SECTOR
FD1(F,G) CHANGE IN FACTOR DEMAND BY SECTOR
UR1 CHANGE IN UNEMPLOYMENT RATE
P1(I) CHANGE IN CONSUMER PRICE OF I
Q1(J) CHANGE IN PRODUCER PRICE OF N
QL1(G) CHANGE IN PRODUCER PRICE LABOR OF BY SECTOR
W1 CHANGE IN NET WAGE
PHI1(G) CHANGE IN PROFIT BY SECTOR
CPI1 CHANGE IN CONSUMER PRICE INDEX
T1 CHANGE IN TAX REVENUE
B1 CHANGE IN TOTAL UNEMPLOYMENT BENEFITS
WRES1 CHANGE IN REAL PER UNIT UNEMPLOYMENT BENEFIT
WNET1 CHANGE IN AFTER TAX REAL WAGE
TNET1 CHANGE IN TAX REVENUE NET OF UE-BENEFITS
TREA1 CHANGE IN TAX REVENUE IN REAL TERMS
GDP1 CHANGE IN GDP IN MARKET PRICES
FINC1 CHANGE IN HOUSEHOLD INCOME NET OF TRANSFERS
U1 CHANGE IN UTILITY;

PARAMETER

TLREV REVENUE FROM TAX ON LABOR INCOME
ITREV INCOME TAX REVENUE
TKREV REVENUE FROM TAX ON CAPITAL INCOME
GTREV COMMODITY TAX REVENUE
TSREV PAYROLL TAX REVENUE
TSCREV C-SECTOR PAYROLL TAX REVENUE
TOTREV TOTAL TAX REVENUE
GEXP TOTAL GOVT EXPENDITURE

```
TLRATE  EFFECTIVE TAX RATE ON LABOR INCOME
TKRATE  EFFECTIVE TAX RATE ON CAPITAL INCOME
HHINC   HOUSEHOLD INCOME
FINC    HOUSEHOLD INCOME NET OF TRANSFERS
TEXP    HOUSEHOLD TOTAL EXPENDITURE
FREV    FIRMS REVENUE
FOUT    FIRMS TOTAL OUTLAY
TEMP    TOTAL EMPLOYMENT
PCEM    PRIVATE CAPITAL EMPLOYMENT
CPIY    PRICE INDEX
CPIX    ALTERNATIVE PRICE INDEX
TLREV0  BENCHMARK REVENUE FROM TAX ON LABOR INCOME
ITREV0  BENCHMARK INCOME TAX REVENUE
TKREV0  BENCHMARK REVENUE FROM TAX ON CAPITAL INCOME
GTREV0  BENCHMARK COMMODITY TAX REVENUE
TSREV0  BENCHMARK PAYROLL TAX REVENUE
TSCREV0 BENCHMARK C-SECTOR PAYROLL TAX REVENUE
TOTREV0 BENCHMARK TOTAL TAX REVENUE
GEXP0   BENCHMARK TOTAL GOVT EXPENDITURE
TLRATE0 BENCHMARK EFFECTIVE TAX RATE ON LABOR INCOME
TKRATE0 BENCHMARK EFFECTIVE TAX RATE ON CAPITAL INCOME
HHINC0  BENCHMARK HOUSEHOLD INCOME
FINC0   BENCHMARK HOUSEHOLD INCOME NET OF TRANSFERS
TEXP0   BENCHMARK HOUSEHOLD TOTAL EXPENDITURE
FREV0   BENCHMARK FIRMS REVENUE
FOUT0   BENCHMARK FIRMS TOTAL OUTLAY
TEMP0   BENCHMARK TOTAL EMPLOYMENT
PCEM0   BENCHMARK PRIVATE CAPITAL EMPLOYMENT
GDP0    BENCHMARK GDP IN MARKET PRICES
ATR0    BENCHMARK AGGREGATE TAX RATE
CPIY0   BENCHMARK PRICE INDEX
CPIX0   BENCHMARK ALTERNATIVE PRICE INDEX;

* Define benchmark solution
TSM.FX(G)=1;
TIM.FX(F)=1;
UR.FX=0.1;
SOLVE ECONOMY USING NLP MAXIMIZING U;

* Save benchmark solution to report parameters
D0(G)=D.L(G);
```

```
X0(G)=X.L(G);
FD0(F,G)=FD.L(F,G);
UR0=UR.L;
P0(I)=P.L(I);
Q0(J)=Q.L(J);
QL0(G)=QL.L(G);
W0=W.L;
PHI0(G)=PHI.L(G);
CPI0=CPI.L;
T0=T.L;
B0=B.L;
WRES0=WRES.L;
WNET0=P.L("L")/CPI.L;
TNET0=TNET.L;
U0=U.L;
TREA0=TREA.L;
TNET0=TNET.L;
TLREV0=SUM(G,TIM.L("L")*TI("L")*W.L*FD.L("L",G));
ITREV0=SUM(G,TIM.L("L")*TI("L")*W.L*FD.L("L",G))
        +SUM(G,TIM.L("K")*TI("K")*Q.L("K")*FD.L("K",G));
GTREV0=SUM(G,TX(G)*Q.L(G)*X.L(G));
TSREV0=SUM(G,TSM.L(G)*TS(G)*W.L*FD.L("L",G));
TSCREV0=TSM.L("C")*TS("C")*W.L*FD.L("L","C");
TOTREV0=ITREV0+GTREV0+TSREV0;
HHINC0=SUM(F,P.L(F)*SUM(G,FD.L(F,G)))+SUM(G,PHI.L(G))+T.L;
FINC0=(SUM(F,P.L(F)*SUM(G,FD.L(F,G)))+SUM(G,PHI.L(G)))/CPI.L;
FOUT0=SUM(G,(Q.L("K")*FD.L("K",G)+QL.L(G)*FD.L("L",G)));
TEXP0=SUM(G,P.L(G)*D.L(G));
GEXP0=T.L;
FREV0=SUM(G,Q.L(G)*X.L(G));
TEMP0=SUM(G,FD.L("L",G));
PCEM0=SUM(G,FD.L("K",G));
GDP0=FREV0+GTREV0;
ATR0=T.L/GDP0;

* Display benchmark solution
DISPLAY "Benchmark solution";
DISPLAY
        X.L, FD.L, PHI.L, D.L, U.L, T.L, TREA.L, CPI.L, P.L, Q.L,
        QL.L, W.L, WRES.L, WNET0, TEMP0, M, UR.L, GDP0, ATR0,
        TX, TI, TIM.L, TS, TSM.L, TLREV0, TSCREV0, TSREV0, GTREV0,
```

```
        TOTREV0, B.L, GEXP0, TNET.L;
DISPLAY HHINC0,FINC0,TEXP0,FREV0,FOUT0,PCEM0;
DISPLAY GAMMA, SIGMAC, DELTA, LAMDA, ALFA, OMEGA, OMEGA2;

* Counterfactual Simulations
* Fix ue-benefit to benchmark level
WRES.FX=WRES.L;

* Counterfactual 1 : Increase in labor income tax, no compensation.
UR.LO=0.01;
UR.UP=100;
TI("L")=1.1*TL0;
SOLVE ECONOMY USING NLP MAXIMIZING U;

* Update report parameters
TLREV=SUM(G,TIM.L("L")*TI("L")*W.L*FD.L("L",G));
ITREV=(SUM(G,TIM.L("L")*TI("L")*W.L*FD.L("L",G))
        +SUM(G,TIM.L("K")*TI("K")*Q.L("K")*FD.L("K",G)));
GTREV=SUM(G,TX(G)*Q.L(G)*X.L(G));
TSREV=SUM(G,TSM.L(G)*TS(G)*W.L*FD.L("L",G));
TSCREV=TSM.L("C")*TS("C")*W.L*FD.L("L","C");
TOTREV=ITREV+GTREV+TSREV;
HHINC=(SUM(F,P.L(F)*SUM(G,FD.L(F,G)))+SUM(G,PHI.L(G))+T.L);
FINC1=(SUM(F,P.L(F)*SUM(G,FD.L(F,G)))+SUM(G,PHI.L(G)))/(FINC0*CPI.L);
FOUT=SUM(G,(Q.L("K")*FD.L("K",G)+QL.L(G)*FD.L("L",G)));
TEXP=SUM(G,P.L(G)*D.L(G));
GEXP=T.L;
FREV=SUM(G,Q.L(G)*X.L(G));
TEMP=SUM(G,FD.L("L",G));
PCEM=SUM(G,FD.L("K",G));
D1(G)=D.L(G)/D0(G);
X1(G)=X.L(G)/X0(G);
FD1(F,G)=FD.L(F,G)/FD0(F,G);
UR1=UR.L/UR0;
P1(I)=P.L(I)/P0(I);
Q1(J)=Q.L(J)/Q0(J);
QL1(G)=QL.L(G)/QL0(G);
W1=W.L/W0;
PHI1(G)=PHI.L(G)/PHI0(G);
CPI1=CPI.L/CPI0;
T1=T.L/T0;
```

```
B1=B.L/B0;
WRES1=WRES.L/WRES0;
WNET1=(P.L("L")/CPI.L)/WNET0;
TNET1=TNET.L/TNET0;
TREA1=TREA.L/TREA0;
U1=U.L/U0;
GDP1=(FREV+GTREV)/GDP0;

* Display counterfactual solution
DISPLAY "uncompensated increase in labor income tax";
DISPLAY X1, FD1, PHI1, D1, U1, T1, TREA1, CPI1, P1, Q1,
    QL1, W1, WRES.L, WNET1, TEMP, M, UR.L, GDP1,
    TX, TI, TIM.L, TS, TSM.L, TLREV, ITREV, TSCREV, TSREV, GTREV,
     TOTREV, B1, GEXP, TNET1;
DISPLAY HHINC,FINC1,TEXP,FREV,FOUT,PCEM;
```

VATT-TUTKIMUKSIA -SARJASSA ILMESTYNEITÄ

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