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Abstract

This article explores the critical role of labour market imperfections in climate stabilisation costs formation. To do so, we use a dynamic recursive energy-economy model that represents a second best world with market imperfections and short-run adjustments constraints along a long-term growth path. We show that the degree of rigidity of the labour markets is a central parameter and we conduct a systematic sensitivity analysis of the model results to this parameter. When labour markets are represented as highly flexible, the model results are in the usual range of existing literature, i.e. less than 2% GDP losses in 2030 for a stabilisation target at 450ppm CO_2 equivalent. But when labour markets rigidities are accounted for, mitigation costs increase dramatically. In a second time, the article identifies accompanying measures, namely labour subsidies, which guarantees against the risk of large stabilisation costs in the case of high rigidities of the labour markets. That vision complements the usual view that mitigation is a long-term matter that depends on technology, innovation, investment and behavioural change. Here we add the warning that mitigation is also a shorter-term issue and a matter of transition on the labour market.

Keywords : *labour market rigidities, climate policies costs, second best world, sensitivity analysis.*

Résumé

Cet article explore le rôle critique des imperfections du marché du travail dans la formation des coûts de stabilisation du climat. A cette fin, nous recourons à un modèle énergie-économie récursif dynamique qui représente un monde « second best » avec des imperfections de marché et des contraintes d'ajustements de court terme sur un sentier de croissance à long terme. Nous montrons que le degré de rigidité des marchés du travail est un paramètre central et nous menons une analyse systématique de sensibilité des résultats du modèle à ce paramètre. Lorsque les marchés du travail sont représentés comme hautement flexibles, les résultats du modèle se situent au niveau habituel de la littérature existante, i.e. inférieurs à 2% de pertes de PIB en 2030 pour un objectif de stabilisation à 450 ppm équivalent CO_2. Mais lorsque les rigidités du marché du travail sont représentées, les coûts d'atténuation s'accroissent de façon spectaculaire. Dans un second temps, l'article identifie des mesures d'accompagnement, à savoir des subventions du travail pour prémunir contre le risque de coûts de stabilisation élevés dans le cas de fortes rigidités des marchés du travail. Cette vision complète la conception habituelle selon laquelle l'atténuation est une question de long terme qui dépend de la technologie, de l'innovation, de l'investissement et du changement des comportements. Ici nous apportons le signal que l'atténuation est aussi un problème de court terme et une question de transition sur le marché du travail.

Mots-clés *: rigidités sur le marché du travail, coûts des politiques climatiques, monde « second best », analyse de sensibilité.*

The costs of climate policies in a second best world with labour market imperfections

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Introduction

There is now a global scientific consensus that halving current world GHG emissions before 2050 is necessary to limit the high risks associated with anthropogenic climate change, and this consensus is flagged as a long run collective target by an increasing number of policymakers. Such a mitigation target will necessarily require deep structural and technological change in the economic production system and in the use of energy, materials and lands around the world. According to the last IPCC report, one can be confident about the feasibility of this challenge thanks to existing or future technologies: the global macroeconomic mitigation cost is estimated below five percent of GDP in 2050, even for the most stringent emission constraints (IPCC 2007). However these IPCC results are submitted to a critical caveat that is precised in Box SPM-3: 'Most models use a global least cost approach to mitigation portfolios and with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century'. Face to these first-best assumptions, one may wonder whether the imperfections of the real world are likely to weaken the robustness of the range of GDP variations due to ambitious mitigation policies.

A significant body of literature is devoted to the analysis of existing market imperfections that are known to raise barriers to the adoption of optimal behaviours and the diffusion of efficient technologies. Notably, the topic has been at the heart of the debate about 'no-regret potentials' that opposed top-down and bottom-up modellers in the nineteen's. While it remains uneasy to identify and assess market imperfections, comparison of the results of optimal planning models on one side and market simulation models[1] on the other side can convey rough ideas on the magnitude of the existing barriers to changes in technology and behaviour.

Beyond that, there may be other imperfections, out of the technological sphere, but also critical, for example on labour, capital and other non energy markets. Disappointingly, those imperfections are insufficiently analysed in the economic literature about climate policies, even though they are likely to condition the efficiency and the net cost of climate policies. The 'visible part' of the iceberg includes carbon leakages (that hangs on both trade and capital flows) and investment crowding-out. Labour market imperfections were also considered in the past but have been almost underwater for a decade.

Indeed, one has to rewind to the double dividend controversy that occurred during the nineties to find several articles that explored the links between mitigation policies and labour market dynamics (Bovenberg and van der Ploeg 1994); (Welsch 1996); (Carraro et al 1996); (Bovenberg and van der Ploeg 1996) (Bovenberg 1999). The general issue was then to determine to what extent the replacement of a fraction of payroll taxes by a CO_2 tax could generate an extra economic benefit that could eventually offset the costs of mitigation. The answer has not been really cleared up, as the assessment of the magnitude of the double dividend critically depends on the intricate representation of the labour market in models.

Since then, few contributions tried and study quantitatively the importance of labour market imperfections on the costs of climate policies. To our knowledge, the study of Babiker and Eckaus (2007) is the most developed, in the sense that the authors (i) recognized the importance of the issue, (ii) modified the EPPA model to assess the impact of sector-specific labour and wage rigidities, (iii) demonstrate that such imperfections may considerably increase mitigation costs, (iv) eventually show that additional appropriate labour policies, namely outplacement assistance and wage subsidies, could offset the cost increase. It may appear surprising that, after this innovative demonstration that labour market dynamics are critical in the assessment of climate policies[2], the EPPA team never used again the modified version of the model in the dozens of that followed.

[1] However it should be noticed that the status of most simulation models is unclear, since they represent perfect markets with no imperfection, but calibrated on real imperfect markets. Their output is then unclear, somehow hybrid between the economic potential –what is profitable- and the market potential -what is achievable with the current conditions.

[2] In another modelling report, the same team recognized that 'a third limitation is that, like capital, labour is treated as being in inelastic supply. This, combined with the full employment assumption that is standard in

By shelving the issue, one runs the risk of missing the appropriate parallel policies that could reconcile employment and climate, and finally ease a safe stabilization of our climate. This article tries and ‘re-open the box’ to explore the critical role of labour market imperfections in climate policy costs. Our approach differs from the previous ones since labour and capital market imperfections are intrinsically represented in our model, Imaclim-R. This model is a dynamic recursive energy-economy model, built to handle three well-known methodological challenges: (i) consistently hybridizing disaggregated technical potentials with general equilibrium constraints (Hourcade and al. 2006), (ii) representing short-run adjustments constraints along a long term growth path (Solow 2000), and (iii) allowing for market imperfections, suboptimalities and adaptive expectations[3]. This new modelling paradigm has been recognized earlier as producing an important transitional slowdown during two decades after the start of stringent climate policies (Edenhofer and al. 2006); (Hourcade and Crassous 2008). As these results are clearly out of the range of other cost assessments in the literature, we have been challenged to identify the very sources of these costs and to understand what policies could smooth the transition while achieving the same environmental results. This exploration led us to understand the critical role of labour market. Technically, in each region of the model, the labour market is modelled through an aggregate regional *wage curve* that links real wages to the unemployment rate (Blanchflower and Oswald 1995).

Assuming that this representation can encapsulate most of labour markets imperfections, we found that the calibration of the wage curve is a critical parameter that could shift the model from our initial high-cost simulations to scenarios in which policy costs are within the usual range. It would be a limited outcome if we had to interpret the sensitivity of the model results to such a hidden and uncertain parameter as a harmful weakness; on the contrary we intend to stress that this sensitivity reveals the importance of labour market dynamics on climate policy costs, which is ignored in all models based on a full utilization of the labour force. While we do not pretend to represent labour market accurately enough to derive precise policy recommendations, our conclusion is that achieving ambitious reductions at a reasonable macro cost, namely within the range of costs assessments gathered by the IPCC, will certainly require specific parallel policies on the labour market. As an example, in the last part of the article, we test a recycling policy that re-allocate the tax revenue to labour subsidies and we find that such a policy succeeds in lowering mitigation costs, whatever the calibration of the wage curve.

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many CGE models, implies that the reduction in labour demand associated with the decline in fossil fuel and energy-using sectors cannot generate unemployment. Instead, the wage falls, allowing the labour market to clear and surplus labour to move to the rest of the economy, where it is re-absorbed.’ (Wing 2004)

[3] IPCC, 2007

This article is organized as follows. The first section comments the literature on the links between climate policy assessments and the representations of the labour market. The second section describes the Imaclim-R model we use in this article. The third section presents and comments simulation results. The last section discusses the results and concludes.

1. Modelling interactions between labour market imperfections and climate policies

1.1 Quick review of the existing models

Almost all numerical models used in climate policy studies assume a perfect labour market and neglect unemployment issues, even complex computable general equilibrium models whose comparative advantage is supposed to represent subtle macro feedbacks. In general, labour supply is equal to active population multiplied by an exogenously increasing productivity, and is fully flexible across all sectors, so that it always remains fully utilized, with its price equalizing its marginal productivity in all (CES) production functions.

Notable exceptions are E3MG (Köhler and al. 2006), SGM (Fawcett and Sands, 2005) and the version of EPPA mentioned in the introduction (Babiker and Eckaus 2007). Technically, in E3MG, employment is output-driven and real wages are linked to the unemployment rate through an econometric equation; in SGM, labour supply stems from a leisure-labour trade-off, while labour demand remains elastic, so that there is no involuntary unemployment; EPPA includes the inertia of inter-sector reallocation and wage rigidities. The next section details Imaclim-R architecture, in which the labour market is also output-driven while real wages are linked to unemployment through regional wage curves.

1.2 The Imaclim-R model: partial factor utilisation and short-run adjustments

a. Model architecture and major features

IMACLIM-R is a hybrid recursive general equilibrium model of the world economy that is split into 12 regions and 12 sectors (Crassous and al. 2006), (Sassi and al. 2009). It is hybrid in two senses: (1) It is a hybrid model in the classical sense: its structure is designed to combine Bottom-Up information in a Top-Down consistent macroeconomic framework. Energy is explicitly represented in both money metric values and physical quantities so as to capture the specific role of energy sectors and their interaction with the rest of the economy. The existence of explicit physical variables allows indeed a rigorous incorporation of sector based information about how final demand and technical systems are transformed by economic incentives. (2) It is hybrid in the sense of Solow (2000)[4], i.e. it tries and bridges the gap between long-run and short-run macroeconomics, as efforts were devoted not only to model long-term mechanisms but also focus on transition and suboptimal pathways through possible underutilization of production factors. We seek, indeed, to capture the transition costs with a modeling architecture that allows for endogenous disequilibrium generated by the inertia in adapting to new economic conditions due to both imperfect foresight and non flexible characteristics of equipment vintages available at each period (putty-clay technologies). In the short run, the main available flexibility lies in the rate of utilization of capacities, which may induce excess or shortage of production factors, unemployment and unequal profitability of capital across sectors.

Technically, the model can be labelled as 'recursive dynamic', since it generates an energy-economy trajectory by solving successive yearly static equilibria of the economy, interlinked by dynamic modules. Within the static equilibrium, domestic and international markets for all *goods* – except *factors* such as capital and labour – are fully cleared by a unique set of relative prices that depend on the behaviours of representative agents on the demand and supply sides. The calculation of this equilibrium determines the following variables: relative prices, wages, labour, quantities of goods and services, value flows.

Within each yearly static equilibrium, the behaviour of producers is not represented by a flexible production function allowing for substitution between factors. These substitutions are treated between two equilibria in sector-specific dynamic modules. Producers are therefore assumed to operate under short-run constraints of (i) a fixed maximal production capacity $Cap_{k,i}$, defined as the maximum level of physical output achievable with the equipment built and accumulated previously, and (ii) fixed input-output coefficients representing that, with the current set of embodied techniques, producing one unit of a good i in region k requires fixed physical amounts $IC_{j,i,k}$ of intermediate goods j and $l_{k,i}$ of labour. In this context, the only margin of freedom of producers is to adjust the utilisation rate $Q_{k,i}/Cap_{k,i}$ according to the relative market prices of inputs and output, taking into account increasing costs when the production capacities utilization rate approaches one[5]. This represents a different paradigm from usual production specifications, since the 'capital' factor is not always fully operated.

Between two static equilibria, technical choices are flexible but they modify only at the margin the input-output coefficients and labour productivity embodied in existing equipment vintages that result from past technical choices. This general putty-clay assumption is critical to represent the inertia in technical systems.

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[4] Solow (2000) : 'I can easily imagine that there is a « true » macrodynamics, valid at every time scale. But it is fearfully complicated [...] At the five-to-ten-year time scale, we have to piece things together as best we can, and look for a hybrid model that will do the job.'

[5] Following (Corrado and Mattey, 1997), we assume that this is generally caused by higher labour costs due to extra hours with lower productivity, costly night work and more maintenance works.

Our model is calibrated on 2001 data from GTAP 6 database (Dimaranan and McDougall 2002) that provides, for the year 2001, a set of balanced input-output tables of the world economy, detailed in 87 regions and 57 sectors. We modified the original GTAP-6 dataset (i) to aggregate regions and sectors according to the IMACLIM-R mapping (ii) to make it fully compatible with the 2001 IEA energy balances[6].

Our model growth engine is composed of exogenous demographic trends (UN World Population Prospects, medium scenario, United Nations, 2005) and exogenous trends of labor productivity, as in Solow's neoclassical model of economic growth (Solow 1956). To build these trends we draw on stylized facts from the literature, in particular the convergence assumption (Barro and Sala-i-Martin 1992) and two empirical analyses on economic convergence, one investigating the past trends by Maddison (1995), and the other one looking at future trends, by Martins and al. (2005). We retained a "leader", the US, whose labor productivity growth trend lies between 2% today and 1.65% in the long run. The other regions labor productivity trends catch up with the leader's, i.e. their labor productivity growth is higher all the more as their absolute labor productivity is far from the leader's level.

The two sets of assumptions on demography and technical change, although exogenous, only prescribe potential growth. Effective growth results endogenously from the interaction of these driving forces with short-term constraints: (i) available capital flows for investments and (ii) rigidities, such as fixed technologies, immobility of the installed capital across sectors or rigidities in real wages, which may lead to partial utilization of production factors (labor and capital). The next section details this last point.

b. Labour market representation

As already mentioned in the previous section, producers operate in static equilibria with a fixed input of labour per unit of output. This labour input, corresponding to labour productivity, evolves between two yearly equilibria following exogenous trends of labour productivity.
Three of the model features explain the possibility of under-utilisation of labour as a production factor, and thus of unemployment. First, rigidity of real wages, represented by a wage curve as we will see in the following, can prevent the wages to fall at the level allowing the labour market to clear. In other terms, the wages are adjusted instantaneously to the economic context in the static equilibrium, but not in an optimal manner. Second, in the static equilibrium, the fixed technologies (Leontief coefficients even for labour input) prevent substitution among factors on the short run. And third, the installed

[6] This process of building hybrid input-output matrices is very precisely discussed in (Sands et al., 2005).

productive capital is not mobile across sectors, which creates rigidities in the reallocations of productions between sectors when relative prices change.

In each region k, each sector employs the labour force $l_{k,i} \cdot Q_{k,i}$, where $l_{k,i}$ is the unitary labour input and $Q_{k,i}$ the production. The unemployment rate z_k is therefore equal to one minus the ratio of employed labour force in all sectors over the total active population L_k:

$$z_k = 1 - \frac{\sum_i l_{k,i} \cdot Q_{k,i}}{L_k}.$$

No endogenous mobility of workers between regions is allowed in the model, thus twelve separate labour markets are represented.

We chose to model labour markets imperfections through an aggregate regional *wage curve* that links real wage levels to the unemployment rate. This representation is based on theories developed in the 80s and early 90s, when a generation of macroeconomic models arose in which an aggregate wage curve, or *wage setting curve*, is the primary distinguishing feature (an overview can be found in Layard et al., 2005; Lindbeck, 1993; or Phelps, 1992). The novel approach of these models, when introduced, was to replace the conventional labour supply curve with a negatively-sloped curve linking the level of wages to the level of unemployment. The interpretation of this wage curve is given either by the bargaining approach (Layard and Nickell, 1986) or the wage-efficiency approach (Shapiro and Stiglitz, 1984). Both interpretations lie on the fact that unemployment represents an outside threat that leads workers to accept lower wages when the threat is important. The bargaining approach emphasize the role of workers (or unions) power in the wage setting negotiations, power which is weakened when unemployment is high. The wage-efficiency approach stands from the firms' point of view and argues the firms set wage levels so as to discourage shirking; this level is lower when the threat of not finding a job back after being caught shirking gets higher. The wage curve specification allows the theories to be consistent with both involuntary unemployment and the fact that real wages fluctuate less than what the paradigm of the conventional flexible labour supply curve gives. Microeconometric evidence for such formulation was given in a seminal contribution by (Blanchflower and Oswald 1995).

In practice, the wage curve for each region in our model is implemented through the relation:

$$\frac{w_k}{pind_k} = aw \cdot \frac{wref_k}{pindref_k} \cdot f\left(\frac{z_k}{zref_k}\right),$$

where w is the nominal wage level, *pind* the consumption price index, z the unemployment rate, *ref* indexes represent the value at the calibration date. By default, *aw* evolves in parallel to the labour productivity so that unitary real wages are indexed on labour productivity. f is a function equal to one when the unemployment rate is equal to its calibration level, and negatively sloped, representing a negative elasticity of wages level to unemployment[7].

There remain important uncertainties on the value to give to the elasticity of wages level to unemployment. By default, we set its value at -0.1 for all regions, which is a value emerging from many econometric studies: (Blanchflower and Oswald 1995), (Nijkamp and al., 2005). But, it is uncertain enough to justify a systematic sensitivity analysis of our model's results, which is the topic of the following section.

2. Numerical experiments and results

2.1 Experimental protocol

We use the model described in previous section to perform two sets of scenarios: a set of 'reference' scenarios, i.e. without climate policies, and a set of '450ppm' scenarios with climate policies starting in 2010 represented by carbon pricing so as to fit a given global emissions profile corresponding to stabilisation target at a concentration of 450ppm all gases.[8] This places us in a "cost-efficiency" context.

For each set of scenarios we run the model with alternative values for the elasticity of the wage curve exploring a wide interval from zero to high values. For each scenario, the wage setting function is thus recalibrated so that it has the chosen elasticity at calibration point. Low values represent very rigid labour markets whereas high values get closer to perfect labour markets. An infinite elasticity would be equivalent to the full employment assumption, but it is not compatible with Leontief specification for the production function. Therefore, we limit the interval and we stop our exploration at the upper value of seven.

2.2 Results

We first show the results of the numerical experiments we conducted in terms of discounted real GDP losses[9] over the period 2010-2050 between each 450ppm scenario and the corresponding reference scenario[10].

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[7] Choosing a functional form and calibrating the function is particularly tricky notably due to the lack of reliable data to fully inform the functioning of the labour markets worldwide. We chose a function of the form $a \cdot (1 - \tanh(c \cdot z))$, and calibrate the parameters a and c so as to have the desired value and elasticity at the calibration point.

[8] By default, the carbon tax revenues are rebated to households in a lump-sum manner.

[9] We measure the real GDP with the Laspeyres index of quantities.

[10] Note that we do not have a single reference scenario but one per value of the elasticity of the wage curve tested. Indeed the elasticity influences the results, GDP growth in particular, in the scenario without climate

Figure 1 presents the global discounted GDP variations over the period 2010-2050 between each of the '450ppm' scenarios, and the corresponding 'reference' scenario with the same wage curve elasticity, plotted against the wage curve elasticity. As it is beyond the scope of this article to discuss what suitable discount rate should be taken, Figure 1 gives the curves for two contrasted discount rates that correspond to the values used by the US Office of Management and Budget to analyze policy decisions (OMB, 2003; see Appendix D, OMB Circular A-4). The discount rate chosen shifts a little the curve up for higher discount rates, but does not change its shape. It clearly appears that the lower the wage curve elasticity, the higher the global GDP losses. This result is not surprising considering that the elasticity of the wage curve determines the balance between the adjustment of the economy in prices (high elasticity) or in quantities (low elasticity). The wage curve could be interpreted as playing the role of a spring anchoring the aggregated production quantities through labour intensity to the value $L_k.(1\text{-}zref_k)$, with a constant spring inversely related to the elasticity of the wage curve (the more the wage curve is elastic, the less the spring is stiff). For a fully flexible wage curve, the aggregate of production quantities is anchored to the $L_k.(1\text{-}zref_k)$ value. The rigidity of the wage curve gives the possibility to move away from the anchor, thus adding to the impact of the reallocation of production across sectors on real GDP, an impact on the general level of activity.

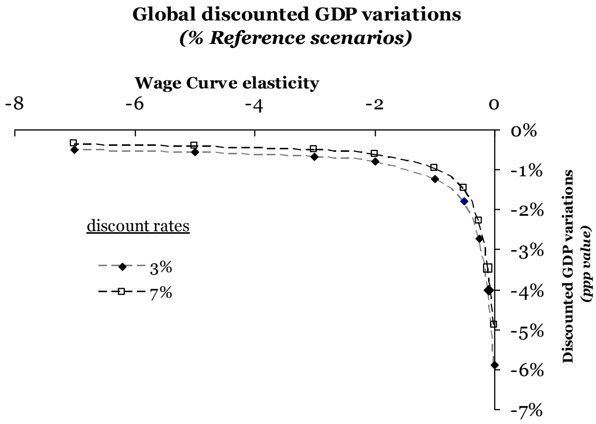

Figure 1 : Global GDP variations discounted over the period 2010-2050 between stabilisation scenarios and corresponding reference scenarios, depending on the wage curve elasticity, and for two discount rates (3% and 7%).

When we get close to fully flexible labour markets (high elasticity, in absolute value), costs are limited, which somehow connects our model's results to existing literature. Using the IPCC AR4 measures, our model results are ranging from 0.5% to 1.5% global GDP losses in 2030 for the wage curve elasticity going from -7 to -1, and form 0.9% to 1.6% in 2050 for the same wage curve elasticity range. It makes our results compatible with the intervals given in the IPCC AR4: 2030 GDP losses

policy as well. Therefore each 450ppm scenario has to be compared with the scenario without climate policy but with the same representation of the labour market, provided that the climate policies do not modify the functioning of the labour market.

ranging from 0.2% to 2.5% in 2030, and from slightly negative (actual gains) to 4% loss in 2050, with median values of 0.6% in 2030 and 1.3% in 2050. It remains that the high values of the wage curve elasticity necessary to replicate IPCC results are not compatible with econometrically estimated values. It is especially true because what matters here is downwards flexibility of wages, which was evaluated to even lower values than upwards flexibility of wages (Akerlof et al. 1996), (Kahn 1997), (Altonji and Devereux 1999) and (Dickens et al. 2007).

When moving to lower values, in absolute value, of the wage curve elasticity (below 1), the slope of the curve is steep and mitigation costs increase dramatically, this interval of wage curve elasticities explored being more compatible with econometrically estimated elasticities.

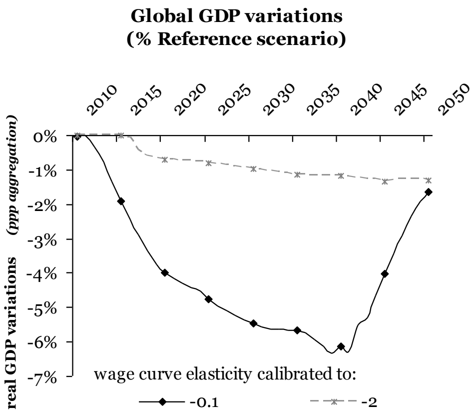

Figure 2 : Global GDP relative variation in ppp values between a stabilisation scenario corresponding to a 450ppm concentration target and the corresponding reference scenario, for two alternative elasticities of the wage curve calibrated to -0.1 (black diamonds) and -2 (grey crosses) respectively.

Figure 2 shows the temporal profile of global GDP relative variation between a stabilisation scenario and the corresponding reference scenario, for two alternative elasticities of the wage curve calibrated to -0.1 and -2 respectively. It illustrates another particularity in our model's results: it exhibits transition costs whereas a majority of models give costs increasing over time. Exploring in detail the issue of the time profile of GDP losses is beyond the scope of this paper, but Figure 2 calls into question the common attitude of most economists who claim to be 'neoclassical on the long run'[11]. When transposed to the field of climate change this attitude leads to use preferably models based on a full utilization of production factors along stabilized growth pathways because climate stabilization is interpreted mostly as a long run challenge while rigidities in the labour market and unemployment are

[11] Solow (2000): ' I can easily imagine that there is a "true" macrodynamics, valid at every time scale. But it is fearfully complicated, and nobody has a very good grip on it. At short time scales, I think, something sort of "Keynesian" is a good approximation, and surely better than anything straight "neoclassical." At very long time scales, the interesting questions are best studied in a neoclassical framework, and attention to the Keynesian side of things would be a minor distraction.'

considered as a short to medium run issue. We argue that this position is restrictive because it does not allow studying the transitional pathways that lead to a low carbon economy. The *goal* of climate policies – avoiding a dangerous climate change – is obviously relevant on the long run only, but climate policies themselves are likely to impact the short and medium run before delivering their final outcome. We demonstrate here that a mechanism considered as purely short-run has impacts over the long-term: stronger rigidities in the labour markets lead to a larger reduction in growth rates over three decades in climate stabilisation scenarios compared to baseline scenarios.

The previous results indicate that stabilisation costs may race out of control in case of high rigidities on the labour markets. For us, these results do not mean that ambitious mitigation actions should not be undertaken because of high mitigation costs, but rather that we should concentrate on how to reduce these costs if they eventually reveal higher than what classical literature gives. More precisely, as there is uncertainty on the functioning of the labour markets today and *a fortiori* on how they will change over time, accompanying measures are needed to reduce the risk of steep increase of mitigation costs. To do so, we focus here on measures that tend to offset the rise in production costs due to carbon pricing and are directed towards labour. In the following, we assess how using carbon tax revenues to lower payroll taxes or subsidise labour[12] changes mitigation costs. Figure 3 shows that

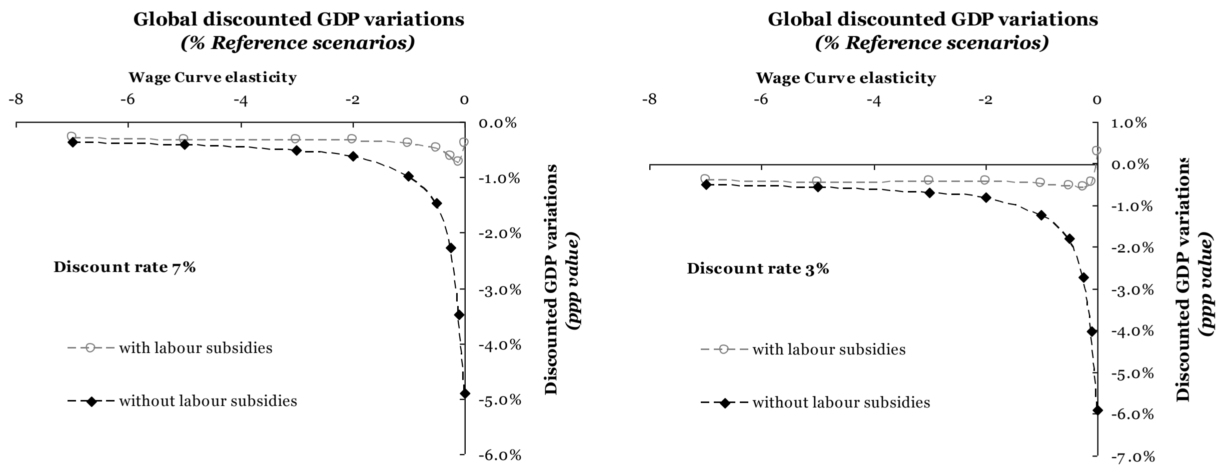

Figure 3 : Discounted global GDP variations between stabilisation scenarios and corresponding reference scenarios, depending on the wage curve elasticity, with (grey rounds) or without (black diamonds) labour subsidies in the stabilisation scenarios, for two discount rates 7% (left panel) and 3% (right panel).

this policy largely offsets GDP losses. The curve of discounted GDP losses as a function of the wage curve elasticity is now almost flat; the steep increase of stabilisation costs when wages are rigid does not occur with the tax-recycling policy tested here. Our results are therefore consistent with the literature on the double dividend and labour market imperfections, which tended to show that the more

[12] By default, the revenues of the carbon tax are rebates to households in a lump-sum manner.

flexible the labour market, the lower the magnitude of the double dividend (Welsch 1996). shows that for very low absolute values of the wage curve elasticity, global discounted GDP variations between the stabilisation scenario and the corresponding reference scenario may even become positive, in the case of a 3% discount rate. This result is due to the facts that in the long run, the stabilisation scenario exhibits actual GDP gains compared to the reference and that the lower discount rate gives more importance to these gains. These GDP gains confirm the fact that our model represents a second best world, or more precisely that our baselines are not optimal in terms of GDP growth.

3. Conclusion

The aim of the study was to understand why our model's results were at the higher end of existing mitigation costs estimations. This led us to show that the representation of rigidities in labour markets is critical in the assessment of mitigation costs. When labour markets are highly flexible, the mitigation costs are very limited in the model (less than 2% real GDP losses in 2050), which brings our results back in the usual range of costs assessments. But these results are based on unrealistic values of the elasticity of the wage curve (especially for downward flexibility). Using more realistic values of this elasticity leads to a dramatic increase of mitigation costs. We admit the use of wage curves is only a very stylised representation of labour markets imperfections; there are many alternative representations of rigidities in wage adjustment (nominal wage stickiness, minimum wage etc) or in labour mobility (costs of labour reallocation across sectors). Nonetheless, in the absence of certainty on the functioning of labour markets, our results constitute a warning that there is a risk that costs might be higher than what current assessments indicate. They call for a cautious assessment of the role of rigidities in the labour markets in the modelling architectures used to evaluate the costs of climate policies.

Our results also demonstrate that, as it was already argued in (Guivarch and al, 2009), mechanisms considered as purely short-term such as maladjustment of the labour markets can have impacts over the long-term. It refutes the common attitude of most climate change economists who neglect short-term mechanisms and use models based on a full utilization of production factors along stabilized growth pathways on the grounds that climate stabilization is a long run challenge.

However, the model in its current form cannot be used to analyse the trade-offs posed by labour market rigidity because it does not take into account all consequences of more or less flexible labour markets. In particular, it does not include the possibility of insufficient demand (in a Keynesian sense), that can make a high flexibility lead to instability and cyclical behaviours. An illustration of this effect is provided by Hallegatte and Ghil (2008), who show how investment flexibility enhances economic resilience to supply-side shocks up to a certain level, beyond which flexibility leads to instability and high vulnerability phases. Moreover, the model does not account for all consequences of a high labour flexibility, especially on income distribution between capital and labour revenues and between skilled and unskilled labour revenues. This distribution, however, has important consequences on inequalities and on the saving ratio (e.g., Pasinetti, 1962; Venieris and Gupta, 1986; Barro, 2000), with potentially significant macroeconomic impacts.

From a climate policy design point of view, the article identifies accompanying measures, namely labour subsidies, which guarantee against the risk that stabilisation costs race out of control in the case of high rigidities of the labour markets. Again, the policy of recycling the carbon tax revenues in payroll taxes reduction or labour subsidies we tested in the model is only a very crude representation of more sophisticated policies that could be implemented to accompany the transition toward low carbon economies. The policy package will probably encompass measures such as continuing education to facilitate professional reconversions, new training offers to meet new demands on the labour market (specialists in buildings energy efficiency) etc. That vision complements the usual view that mitigation is only a matter of technology, innovation, investment and behavioural change. It has already been emphasized that climate policy costs will depend on subtle mechanisms such as induced technical change and innovation (Arthur, 1989), international trade feedbacks (McKibbin and al. 2000) or expectations' formation (Paltsev et al. 2009). Here we add the warning that mitigation is also a matter of labour market transition; a transition that can be made easier by specific collateral policies that need to be assessed. Ignoring them could result in much larger costs that what most models suggest.

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