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Unemployment Effects of Climate Policy

Mustafa Babiker and Richard S. Eckaus

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To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

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Unemployment Effects of Climate Policy

Mustafa Babiker[†] and Richard S. Eckaus[*]

Abstract

This paper models the unemployment effects of restrictions on greenhouse gas emissions, embodying two of the most significant types of short term economic imperfections that generate unemployment: sectoral rigidities in labor mobility and sectoral rigidities in wage adjustments. A labor policy is also analyzed that would reduce the direct negative economic effects of the emissions restrictions.

The politics of limiting greenhouse gas emissions are often dominated by relatively short term considerations. Yet the current economic modeling of emissions limitations does not embody economic features that are likely to be particularly important in the short term, in particular, the politically sensitive unemployment rate. Moreover, only a few of these studies also consider policies that would offset the negative direct economic effects of emissions restrictions. For plausible estimates of the parameters, the model shows that, with the labor market imperfections, if there were no offsetting policies, the reductions in GNP in the U.S. in the first ten years after emissions restrictions were imposed would be as much as 4 per cent. However, if there were two policies, instead of just one: a counteracting labor market policy, as well as the emissions restrictions, the negative direct economic effects could be completely eliminated.

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1. INTRODUCTION

The politics of limiting greenhouse gas emissions are often dominated by relatively short run considerations: their economic effects over, say, the next five years, which is the time horizon of much electoral contention. There is, for example, the characterization from the *New York Times*:

> "Mr. Bush has resisted serious action on global warming on the basis that strong measures 'would have wrecked our economy'."[1]

The warning from President Bush was not about consequences in 2100 but about effects to be expected in the next few years after emissions constraints were imposed.

The current economic modeling of emissions limitations does not embody those economic features that are likely to be particularly important in the short term and, as a result, has had little

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[1] Kristof (2005).

to say about short term issues.[2] Moreover, while the analyses in the current modeling studies impose the structural burden of greenhouse gas emissions restrictions, only a few of these studies also consider policies that would offset the effects of those restrictions.

This paper has a different focus. While not including all the influences that are important in macroeconomic analyses, it does embody two of the most significant types of economic rigidities in a computable general equilibrium model which is used to project greenhouse gas emissions. These are: sectoral rigidities in labor mobility and sectoral rigidities in wage adjustments. Our analysis will show that these rigidities are significant factors in determining the character of the economic adjustments to emissions limitations. A labor subsidy policy that would reduce the direct negative economic effects of emissions restrictions is also analyzed.

Policies to limit greenhouse gas emissions are, in effect, structural changes in an economy, whether the policy is a change in market prices created by emissions limits and trading in permits or by direct controls. Both would create new and long lasting reductions in output and changes in input prices requiring, in turn, new types of adjustments. It is, therefore, important to consider policies that offset these reductions. This is all the more urgent when the effects of labor market imperfections are taken into account.

The effects of structural conditions on employment and output have been the subject of much research, resulting in a rich macroeconomics literature on various labor rigidities and labor market imperfections and their consequences. The following statement, for example, is not unusual.

> "Worker-job matches are fragile. In addition to aggregate demand fluctuations, the economy is continuously subject to economic forces that destroy matches only in certain firms or sectors and require labor to be redistributed to other firms or sectors."[3]

Much of the relevant macroeconomic literature has focused on estimating the NAIRU, the Non-Accelerating Inflation Rate of Unemployment, which is a rate of structural unemployment, as distinct from the unemployment resulting from economic cycles of recession and expansion that, in turn, give rise to changes in the rate of inflation. In the U.S. the estimated NAIRU has varied between 5.4 to 6.5% until the late 1990s, when it fell well below 5% (Gordon, 1997). The variation has been ascribed to changes in international competition, the bargaining power of labor and the rise and decline of major industries, the burgeoning of the electronics industry being one of the frequently cited influences. Because the NAIRU reflects major adjustments that are difficult to predict, the estimation of the NAIRU has, for the most part, been *post hoc*. By comparison, in the modeling of greenhouse gas emissions and limitations and related costs the expected structural change is explicit.

The economic modeling techniques that are currently used to project emissions and the effects of their limitations, whether "top down" or "bottom up," for the most part, assume, implicitly or explicitly, the existence of instantaneous and perfect markets in inputs and outputs. The necessary economic adjustments, therefore, take place smoothly and completely within each

[2] For typical examples of such models see Weyant and Hill (1999).
[3] Haltiwanger and Schuh (1999).

period.[4] So the models pass over the consequences of the various rigidities that actually exist in all economies. This is often justified, either implicitly or explicitly, by the focus on the longer run implications of mitigation policies and the consequent simplification of the modeling process, even though unemployment may continue to occur.[5]

The EPPA model of the Joint Program on the Science and Policy of Climate Change, which is a recursive, dynamic computable general equilibrium model, provides a convenient platform for the analysis of rigidities in the economy. EPPA is, perhaps, unique among emissions predictions models in recognizing three types of major rigidities that will impede adjustments to the structural changes involved in policy changes that restrain emissions. These are: (1) the existence of vintages of capital stocks with different productivities, (2) limitations on the flexibility of capital stocks in moving among economic sectors, and (3) limits on the speed with which unconventional energy sources and technologies can be utilized. However, EPPA does not as yet take into account the rigidities that limit the ability of labor to move among sectors as the demands for sectoral output change over time and in response to emissions limits. These rigidities may be thought of also as the result of the tying of some specific labor skills to a particular sector. Farmers cannot easily become electronic specialists; coal miners cannot easily move to newly expanding industrial sites, and industries are slow to move to labor surplus areas.

While more sophisticated in most respects than other economic models used to project emissions and the consequences of policies to reduce them, the EPPA model is still far from ideal for the present application. The model's lack of forward looking dynamics and associated expectations, of a monetary framework, and of a realistic foreign trade structure are particularly significant. Another drawback of the EPPA model for the present purposes is that it has a five year time period, which is much longer than conventional estimates of the mean employment adjustment period.[6] However, the conventional estimates are usually associated with cyclical unemployment and do not apply to changes in which jobs are permanently destroyed by structural changes in the demand for labor in particular sectors. We attempt to adjust for this by making moderate assumptions about the proportions of labor assumed to be specific to the sector.

The following section describes the specific characteristics of labor immobility and wage rigidity that are investigated in the model solutions. Section 3 describes the model briefly and Section 4 discusses prominent characteristics of the model solutions. Section 5 concludes.

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[4] The vintaging of capital stocks is an exception to this practice, but it is embodied in only a few of the models used to project the costs of limiting greenhouse gas emissions.

[5] It might be argued that the models recognize structural unemployment implicitly because they calibrate the productivity of the total labor force to the initial year's total output. An explicit recognition would require the calibration of productivity to the actually employed labor force and initial year's output. This would recognize the existence of some initially unemployed labor. However, neither approach requires the adjustment of employment for subsequent structural changes.

[6] Unemployment rates do not measure the proportions of all workers who have been displaced by technological change or shifts in demand, as some stop looking for jobs, temporarily or permanently. The proportion of displaced workers who were unemployed more than 52 weeks or not in the labor force from 1981 to 1985 was almost 53% (Horvath,1987).

2. CHARACTERIZATION OF LABOR INFLEXIBILITIES

Unemployment is generated in the model by two characterizations, applied in different combinations[7]. The first is that there is an exogenously determined fraction of sectorally specific labor which does not leave the sector in the same period in which the demand for that labor has fallen, because of decreased demand for the sector's output or any other cause. It is only in the next period that the sectorally specific labor moves to another sector whose labor demand increases. The second characterization is that the labor market does not clear immediately through flexible wages when the demand for the labor falls. The inflexibility of nominal wages has, of course, been a prominent part of macroeconomic analysis since Keynes and the characterization appears too frequently to be worth citing a single source. Although the characteristic has been relied upon less frequently in recent analysis, it has appeared again in an important new paper (Blanchard and Gali, 2005).

We have considered the implications of two types of wage rigidity. In one type nominal rigid wages for sector specific labor are kept at the 1997 level from which the model solutions start. Even when workers in economic sectors that declining, relatively or absolutely, and are unable or unwilling to move into more rapidly growing sectors, they may still be able to maintain their wages at the levels of mobile labor. This may be the result of union contracts that fail to accommodate changes in industry demands or technology, a not unusual condition. The other type of wage rigidity keeps the wage of sector specific labor at the economy wide wage, even though the sectoral demand for that labor has dropped. In this formulation the sector specific labor will ask for the same change in its wage level as that of the mobile labor. This may be the result of union wage negotiation or the prevalence of industry patterns that maintain an equivalence of wages in particular regions. Only examples of the first type of wage rigidity will be reported on here, since the consequences of the latter type are broadly consistent with the implications of the first type.

A major problem for us in implementing these labor market features in EPPA is the lack of data on the specificity of labor and the degree and timing of labor frictions in the face of structural changes. As noted, both types of labor market imperfections can be expected to be different than conditions resulting from cyclical changes. A similar data problem exists in the modeling of capital vintages and intersectoral capital flexibility. With respect to both the limited capital flexibility conditions and the limited labor flexibility condition, ignoring the imperfections would amount to assuming complete flexibility. That is patently incorrect. To avoid this error, the same approach is used with respect to labor rigidities, as was used with respect to capital rigidities: some assumptions about magnitudes are made that seem plausible. This is a case, however, in which the plausibility of the assumed data inputs has to be judged, in part, by the plausibility of the consequent solutions that result. And that will have to await the presentation of the results and

[7] Unemployment, as conceived of here, corresponds most closely to the, "displaced worker," concept of the U.S. Bureau of Labor Statistics whose unemployment is due to technological change and/or changes in demand. It includes both workers out-of-work, but looking for a job and workers who have lost jobs and withdrawn from the labor force.

the readers' judgments. These assumptions cannot be justified rigorously. They are based on some knowledge of the occupational structures of the industries, but will not be defended forcefully. They are intended to be modest and illustrative assumptions. The proportions of sector specific labor in the various sectors are assumed and the values are shown in **Table 1**.

Table 1. Proportions of Specific Labor By Sector.

	Developed countries	Less developed countries
Agriculture	15 %	25%
Crude oil	15%	20%
Natural gas	10%	15%
Coal mining	20%	25%
Refined oil	15%	15%
Electricity	12.5%	12.5%
Energy intensive industries	15%	15%
Other industry	15%	15%
Services	10%	10%
Transport	10%	10%

The next section will describe the structure of the EPPA model which is used for the analysis, but only briefly, because more detailed descriptions exist in the published literature (Paltsev et al., 2005). The modifications that have been made to EPPA for the present purposes will then be described in somewhat more detail. The third section will present the main results of the alternative solutions with the parameters as specified above.

3. THE EPPA MODEL

For complete description of the MIT Emissions Prediction and Policy Analysis (EPPA) model, its parameters and its applications, see Babiker et al. (2001) and Paltsev et al. (2005). The EPPA model is a part of a larger Integrated Global System Model (IGSM) that predicts the climate and ecosystem impacts of greenhouse gas emissions (Sokolov et al., 2005), but for this study it is run in stand-alone mode.

The EPPA model is built on the GTAP data set, which accommodates a consistent representation of energy markets in physical units as well as detailed accounts of regional production, consumption and bilateral trade flows for more than 80 countries and regions in the world (Hertel, 1997; Dimaranan and McDougall, 2002). In addition to economic data EPPA incorporates data on the major greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) as well as other gases and aerosols (SO_2, NO_x, CO, NH_3, VOC, black carbon, and organic carbon) emissions. For the purpose of this study our focus is on CO_2 emissions.

The EPPA model aggregates the GTAP dataset into 16 regions and 10 sectors, listed in **Table 2**. The model's base year is 1997. From 2000 onward the model is solved recursively at 5-year intervals. Because of its focus on climate policy, the model disaggregates the energy supply technologies and includes a number of backstop energy supply technologies that were not in general use in 1997 but could potentially be used and would take market share in the future, in the face of changing energy prices or climate policy conditions.

Table 2. Countries, Regions, and Sectors in the EPPA Model.

Country or Region	Sectors
Annex B	**Non-Energy**
United States (USA)	Agriculture (AGRI)
Canada (CAN)	Services (SERV)
Japan (JPN)	Energy Intensive products (EINT)
European Union[a] (EUR)	Other Industries products (OTHR)
Australia/New Zealand (ANZ)	Transportation (TRAN)
Former Soviet Union[b] (FSU)	**Energy**
Eastern Europe[c] (EET)	Coal (COAL)
Non-Annex B	Crude Oil (OIL)
India (IND)	Refined Oil (ROIL)
China (CHN)	Natural Gas (GAS)
Indonesia (IDZ)	Electric: Fossil (ELEC)
Higher Income East Asia[d] (ASI)	Electric: Hydro (HYDR)
Mexico (MEX)	Electric: Nuclear (NUCL)
Central and South America (LAM)	Electric: Solar and Wind (SOLW)
Middle East (MES)	Electric: Biomass (BIOM)
Africa (AFR)	Oil from Shale (SYNO)
Rest of World[e] (ROW)	Synthetic Gas (SYNG)

[a] The European Union (EU-15) plus countries of the European Free Trade Area (Norway, Switzerland, Iceland).
[b] Russia and Ukraine, Latvia, Lithuania and Estonia (which are included in Annex B) and Azerbaijan, Armenia, Belarus, Georgia, Kyrgyzstan, Kazakhstan, Moldova, Tajikistan, Turkmenistan, and Uzbekistan which are not. The total carbon-equivalent emissions of these excluded regions were about 20% of those of the FSU in 1995. At COP-7 Kazakhstan, which makes up 5-10% of the FSU total, joined Annex I and indicated its intention to assume an Annex B target.
[c] Includes a number of former Yugoslav republics and Albania not Part of Annex B, which contribute only a small percentage of the overall emissions of the Region.
[d] South Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand
[e] All countries not included elsewhere: Turkey, and mostly Asian countries.

Engineering details are incorporated in EPPA in order to represent the alternative energy supply technologies. The synthetic coal gas industry produces a perfect substitute for natural gas. The oil shale industry produces a perfect substitute for crude oil. All electricity generation technologies produce perfectly substitutable electricity except for the Solar and Wind technology, which is modeled as producing an imperfect substitute, reflecting their intermittent outputs.

Production technologies are described as nested CES functions. The nesting structure was designed to allow flexibility in setting elasticities of substitution particularly with regard to the use of fuels and electricity, as well as other substitutions to which emission and abatement costs are especially sensitive. The production structure for electricity is the most detailed among the sectors because of its importance in energy use and emissions. The top level nests allow treatment of different generation technologies. These include generation technologies that exist in the base year data (conventional fossil, nuclear, and hydro) and advanced technologies that did not exist in the base year. The lower nests represent the structure within particular generation technologies.

The uses of conventional fossil fuels are not represented separately as coal, oil, and gas technologies, but instead these alternative fuels are treated as direct substitutes. This has the advantage of making it possible to directly control the potential substitution among fuels, thus representing their unique values for peaking, intermediate, or base load uses. Nuclear and hydro power have much simpler structures, focusing on the relevant resource fore each, as well as capital and labor requirements. For both, the resource is represented as a fixed factor endowment specific to the technology and region. Primary energy sectors (coal, oil, and gas) have structures similar to those of most other sectors of the economy with the exception that at the top nest a fuel specific resource is included with a substitution elasticity to control the short run supply (i.e., the rate of production from the resource).

Factors of production in the model include labor, capital, land and the separate fuel resources. Fossil fuel resources are calibrated to yield exogenously specified supply price elasticities of the corresponding fossil commodities. The supplies of these fossil resources are updated after each period according to a depletion module based on the levels of production in the previous period. In the standard version of EPPA, the labor market is assumed to clear instantaneously and labor is modeled as perfectly mobile across sectors in the economy though immobile across regions. The stock of labor is updated after each period exogenously to account for population and productivity growth. EPPA distinguishes between two types of capital: malleable and vintaged. Malleable capital is modeled as perfectly mobile across sectors but not across regions and is updated exogenously after each period depending on the level of investment in the previous period. For modeling of vintaged capital, EPPA is unique in incorporating an elaborate structure of vintaging in which five vintages of sector specific capital are carried, each subject to depreciation.

International trade in all goods, except crude oil, is represented in EPPA by an Armington structure in which domestically produced goods and foreign produced goods are treated as imperfect substitutes. Crude oil is exported and imported as a perfectly homogenous product. The Armington specification allows an explicit representation of bilateral trade flows, calibrated to the base year, 1997, such that regions are both exporters and importers of a particular good. All international trade, including trade in crude oil, is subject to export taxes, import tariffs and international transport margins, all of which are explicitly represented in the model.

EPPA assumes a representative agent in each region, whose preferences are described by a nested CES function. Saving enters directly in the top nest of the utility function, which generates the demand for savings and makes the consumption-investment decision partially endogenous in the model. The lower layers in the utility function include an energy nest, a nest for non-energy consumer goods, and a nest for household transportation. The energy nest excludes purchases of transport fuels, however, as those are treated explicitly in the transport nest. To capture the non-constant returns to scale aspect of consumption, consumption shares in each period are updated according to the per-capital income growth between periods. This treatment is intended to mirror demand relationships originally proposed by Frisch (1959) where the substitution elasticity also depends on income.

The EPPA model is formulated and solved as a Mixed Complementarities Problem (MCP) using the GAMS-MPSGE system (Rutherford, 1995).

4. MODELING OF LABOR SECTOR-SPECIFICITY AND UNEMPLOYMENT

As noted, we distinguish between two types of labor: mobile labor and sector-specific labor. The initial supply of sector-specific labor is computed from the proportions in Table 1 and both sector-specific and mobile labor are exogenously updated after each period to account for productivity growth.

Nominal wage rigidity in each sector is imposed by a wage floor equivalent in the base year, 1997, for the specific labor type in each sector. These wage rigidities are implemented in the model through endogenous side constraints with the market closure for specific labor being changed from instantaneous clearance to one which allows for unemployment. These constraints force endogenous adjustments until the imposed wage constraint is satisfied in equilibrium with the excess labor supply becoming the size of unemployed sector-specific labor. The national rate of unemployment is computed each period by relating the total number of unemployed sector-specific labor to the aggregate supply of labor (both mobile and immobile). Further, a labor reabsorption rate of 75% is assumed in modeling unemployment, i.e., 75% of the unemployed sector-specific labor is absorbed by the next period.

To explore a potential domestic policy that would ameliorate the negative impacts of climate policy on employment, we consider the impacts of a labor subsidy. First, we add to the model a labor transformation activity that transforms sector-specific labor into mobile labor. This in essence might represent an activity that provides training to sector-specific labor so that it can be matched to jobs in sectors in which output grows even in the event of the implementation of a climate change policy. The transformation activity involves the additional cost of training and skills upgrading, which, for convenience, is calibrated in its production technology to be initially equivalent to the average wage wedge between sector-specific labor and mobile labor along the reference solution of the model version without unemployment. Further, this cost is represented as purchases from the “other industry” sector in the model. Second, we analyze two subsidy schemes: an endogenous subsidy and an exogenously stipulated one. The rate of the endogenous subsidy is determined within the model by means of a side constraint that requires that the unemployment rate under the climate policy should not exceed that along the reference solution for the model version with unemployment. In the exogenous subsidy version of the model, subsidy rates of 15% for coal, 10% for gas, refined oil, and electricity, and 5% for the rest of the sectors are used. These subsidy rates are represented explicitly in the model but are active only when climate policy is in effect.

5. COMPARISONS OF SOLUTION RESULTS FOR NONSPECIFIC AND SPECIFIC LABOR AND FLEXIBLE AND RIGID WAGES

Four types of solutions are compared in this section:

(1) Under the conventional assumption of mobile labor and flexible wages;

(2) With the condition of sector specific labor, but flexible wages;

(3) With mobile labor, but rigid wages;

(4) With both sector specific labor and rigid wages.

In turn, these different types of solutions are calculated separately under three alternative conditions:

(1) As if there were "business as usual," i.e. with no greenhouse gas policy restrictions, which is called the Reference Solution;

(2) With Kyoto-like emissions restrictions imposed, but also without any offsetting policies;

(3) With the Kyoto emissions restrictions, but with labor subsidies to offset the unemployment and economically depressing effects of those restrictions.

Implementing the rigid wage condition is a bit tricky in the EPPA model in which labor augmenting productivity change is one of the primary drivers of economic growth. That assumption implies a continuous increase in labor supply in efficiency units and accordingly a downward pressure on the unit labor price in both nominal and real terms. If this adjustment were not made, the character of the model would have to be completely changed. Therefore the nominal wage rigidity assumption that is implemented in the solutions only restricts the rate of reduction of the nominal wage that would otherwise occur when emissions restrictions are imposed. Nominal wages in OECD countries are not allowed to fall by more than 1% per annum, while in developing countries and transitional economies, nominal wages are not allowed to fall by more than 2% per annum.[8]

5.1 The Effects of Unemployment When There Are No Emissions Restrictions

Figure 1 shows the percentage differences in projected levels of conventionally estimated GNP in the Reference Solutions for the various countries, without and with the assumptions of sector specific labor and rigid wages. The results are presented in this way because overall

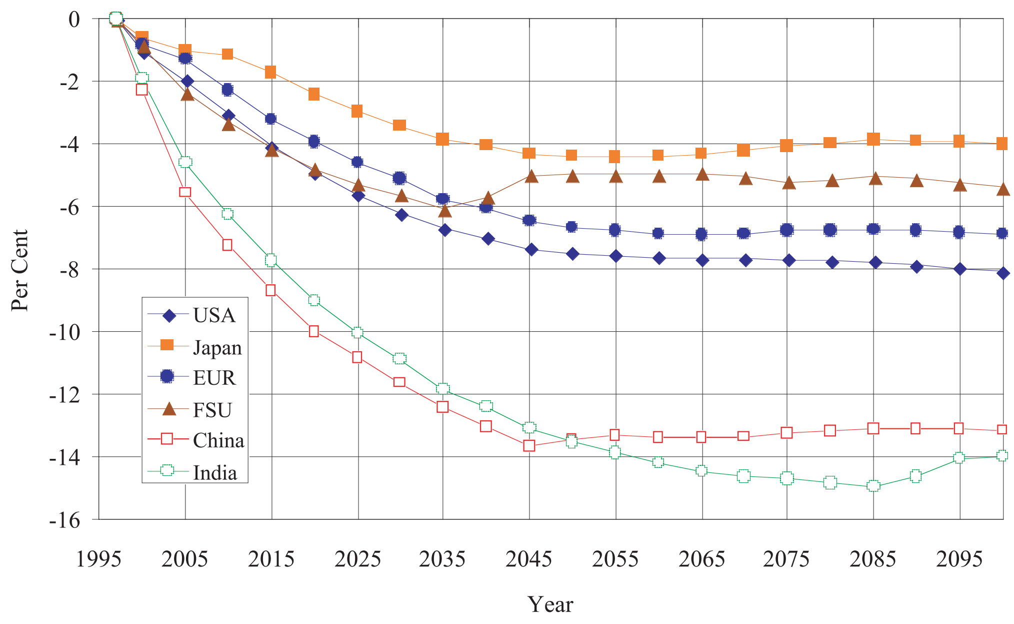

Figure 1. Differences in levels of GNP of reference solution with sector specific labor and rigid wages versus reference solution with mobile labor and flexible wages.

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[8] In describing the results of the various solutions, the metric that is used most frequently is the associated level of GNP. Thus the effects on the "green GNP," which takes into account the depletion of natural resources and the benefits of greenhouse gas reductions are not taken into account. That is not because these effects are regarded as insignificant, but rather reflects the current inability to quantify the effects under alternative conditions.

economic growth proceeds, by assumption, in both types of solutions. The labor market imperfections result in distinctly lower GNP levels in all countries, even when there are no policies to restrict emissions. The labor market imperfections generate unemployment, even in this Reference Solution, without emissions restrictions. This result would not surprise a macroeconomist, who is accustomed to thinking about the effects of wage rigidities, but might impress emissions model builders. The general rationale for the negative effects of the rigidities is that growth requires changes in the relative importance of the various sectors, with resulting requirements for the shifting of labor among sectors. When that shifting is constrained, so is output and income.

The differences start out small, though significant in the early years in all the countries and grow to large differences by 2030. For the U.S., when there are sector specific labor and rigid wages, the GNP is reduced about 1% every five years, until about 2025, when the annual differences become smaller, though still noticeable. After about 2050, the differences in the two types of solutions stabilize at about 7.5%. By that year the economies have settled into their persistent patterns, with relatively little subsequent change in sectoral output patterns that, in turn, would require labor shifting. The smallest differences are in Japan and the largest in China and India. Although the shares of specific labor are assumed to be the same in most sectors, in China and India, the economic transformations associated with growth would require relatively larger sectoral shifts in their labor forces. When those shifts are constrained, the economic losses are greater. In Japan relatively small changes are projected in the projected sectoral patterns of output and employment, so the effects of sector specific labor and rigid wages are, in turn, relatively small. The patterns of differences in other countries fall between Japan, on the one hand, and China and India on the other hand.

Figure 2 shows the unemployment in the Reference Solutions that is projected to result from the immobility of labor and rigid wages. The different unemployment rates across countries

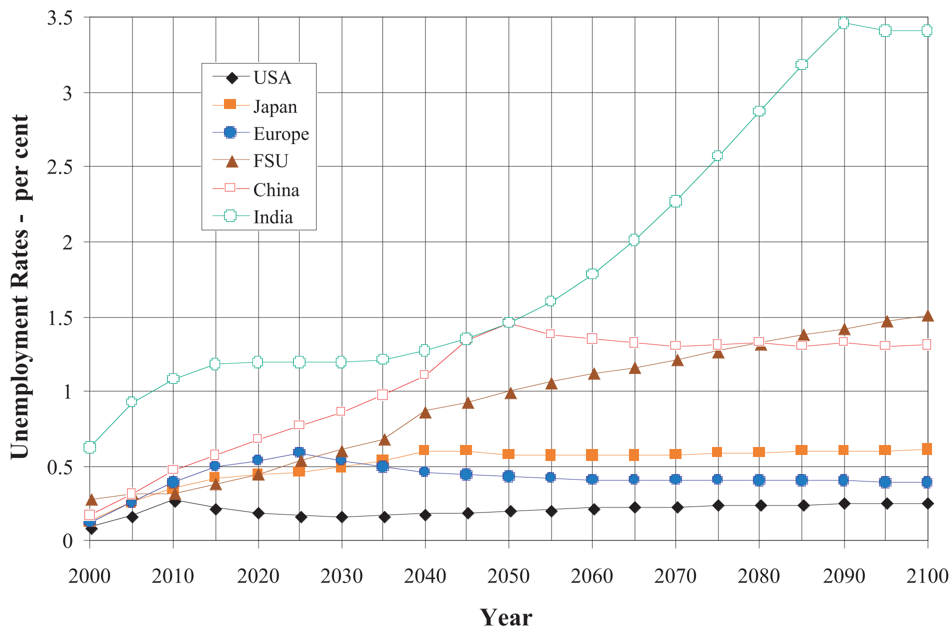

Figure 2. Unemployment in reference solutions due to specific labor and rigid wages.

reflect the differences in the sectoral distributions of output and employment and the different sectoral adjustments that would be generated by growth in each country. The unemployment rates are relatively modest except in China and India. Although the immobility of labor and rigid wages restrict the labor adjustments, the potential for adjustment in the intensity of use of capital is sufficiently great so that, in most of the other countries, it is not necessary to leave much labor completely idle.

The effects of both types of labor market imperfections on CO_2 emissions are shown in **Figure 3**, comparing the Reference Solution with sector specific labor and rigid wages with the Reference Solution without these labor market imperfections. The pattern of relative CO_2 emissions is generally similar to the pattern of relative GNPs in the first twenty years, as would be expected. However, the reductions in CO_2 emissions are not as great as the reductions in GNP created by the labor market imperfections. In both situations the economies are adjusting to the increasing costs of energy over time, but the labor market imperfections hinder this adjustment and, therefore, emissions from fossil fuels are not reduced as quickly. A little reflection suggests that these results should be expected. Since the labor market imperfections reduce output, emissions are also reduced.

In order to compare the relative effects of sectorally specific labor and rigidity in wages, solutions for each condition were calculated separately. **Figure 4** presents the differences in the reference solutions with sector specific labor and flexible wages versus the reference solution with mobile labor but rigid wages. Both types of labor market imperfections would reduce GNP. However, as Figure 4 shows, wage flexibility permits a higher level of output than labor immobility in the USA, Europe and Japan until about 2065, although the differences in Japan are relatively small. The differences in the FSU are small, while the differences in China and India are quite large for most of the century. However, it is undoubtedly true that the comparisons could be reversed for other choices of the parameters.

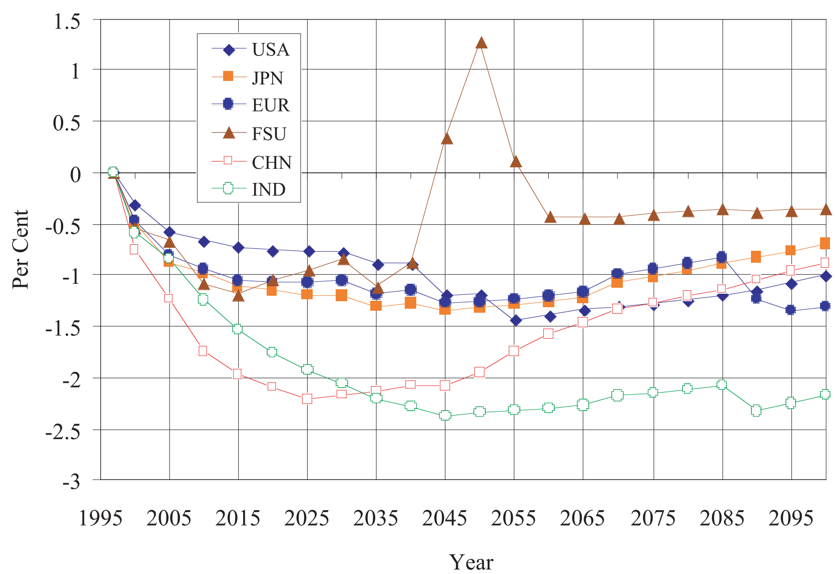

Figure 3. Differences in CO_2 emissions in reference solution with sector specific labor and rigid wages versus reference solution with mobile labor and flexible wages.

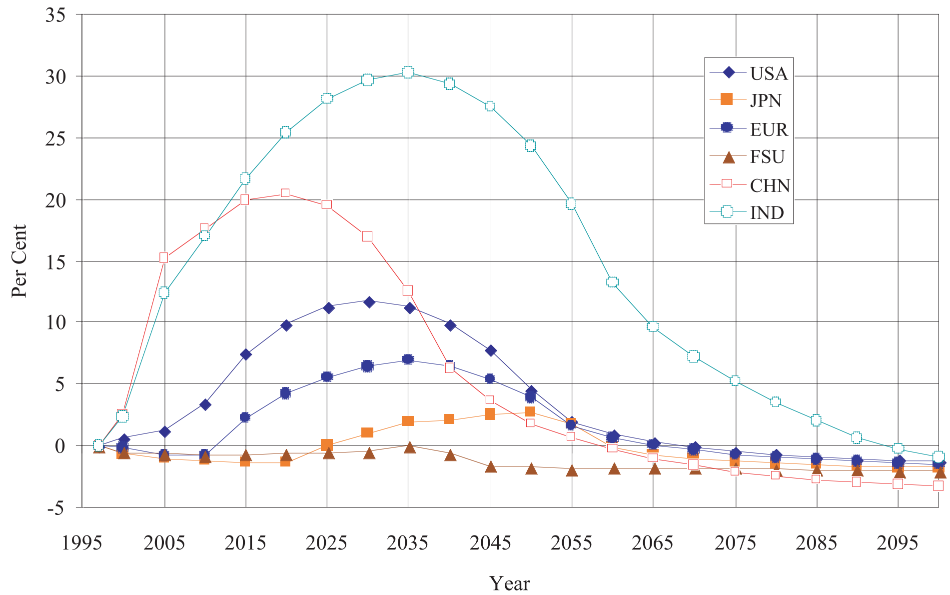

Figure 4. Comparison of GNP in reference solutions with mobile labor and flexible wages minus GNP with sector specific labor and rigid wages.

5.2 The Overall Consequences of A Kyoto-like Policy to Reduce Emissions

The next set of comparisons takes into account the direct consequences of constraining emissions to their 2000 level for the US and imposing the Kyoto Protocol caps for other Annex B regions, starting in 2010 and through 2100. To make the comparisons, solutions are first calculated with the emissions restrictions policies imposed and then compared with solutions without those restrictions, both without labor market imperfections. The results are shown in **Figure 5**. This is the comparison that is usually made in analyzing the cost of emissions restrictions. For the U.S. the costs are relatively minor, at least for the first twenty-five

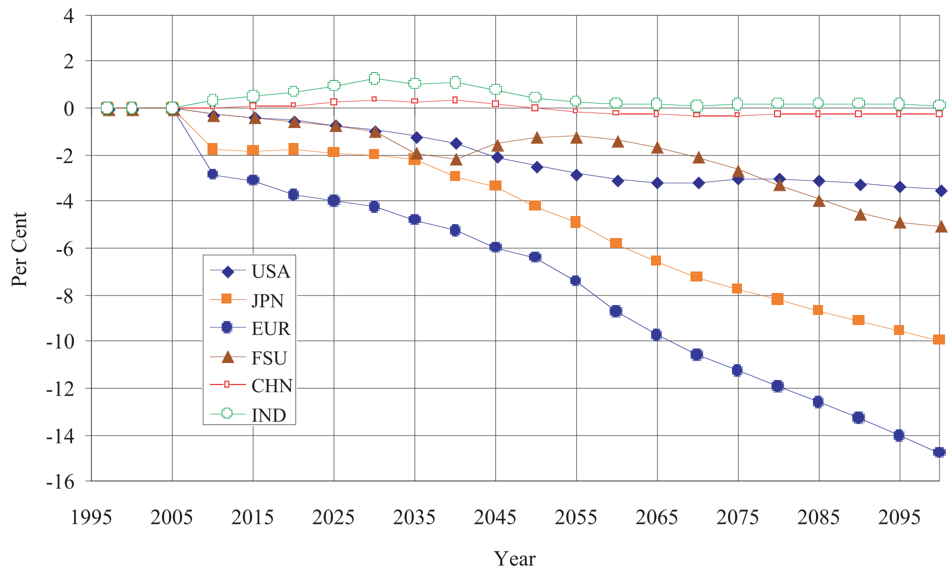

Figure 5. GNP in reference solutions compared to GNP in policy solutions, both without labor market imperfections.

years, ranging from less than 0.5% in 2010 to 2% in 2045. The foregone GNP resulting from the emissions constraints is substantially higher in Europe and, for Japan, in between the U.S. and Europe. China and India gain quite a bit from the redirection of trade.

It is useful to compare Figure 5, where the differences between solutions are the result of emissions restrictions policies, with Figure 1, where the differences are due only to the labor market imperfections. The market imperfections are more deleterious in the U.S., the FSU, China and India than the emissions policy restrictions would be, and less so in Europe and Japan and the rest of OECD where the emission restrictions are more stringent. Emissions restrictions policies would have no direct impact on China and India, but imperfections in their labor markets would. These observations indicate the importance of the economic structure of an economy for projecting the effects of different policies.

When the comparisons are made between policy and reference solutions, now both with the labor market imperfections, the results in **Figure 6** are virtually the same as in Figure 5, with differences appearing mainly in the last quarter of the century. This indicates that the emissions restrictions alone would not generate substantial reallocations among sectors. If those were necessary, the labor market imperfections that impede them would create more noticeable costs in foregone GNP.

This does not imply that the absolute reductions in GNP due to the policy restrictions are the same. **Figure 7** demonstrates this by comparing the GNP in policy solutions with and without the labor market imperfections. It is clear from the figure that the labor market imperfections impose greater losses in GNP.

Figure 8 indicates the differences in the shadow price of carbon as a result of labor market imperfections, when there are no emissions restrictions.

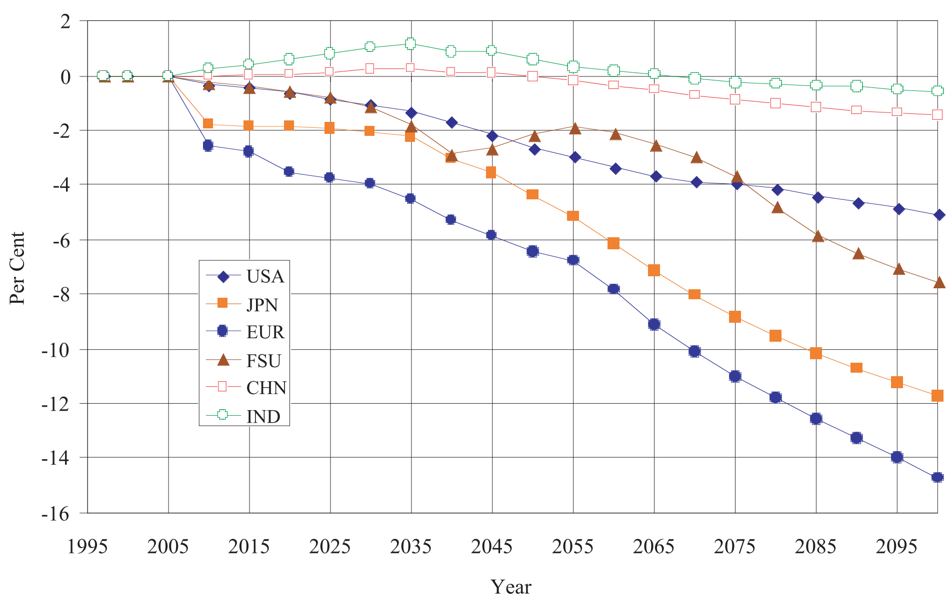

Figure 6. GNP in reference solution with sector specific labor and rigid wages minus GNP in policy solution with sector specific labor and rigid wages.

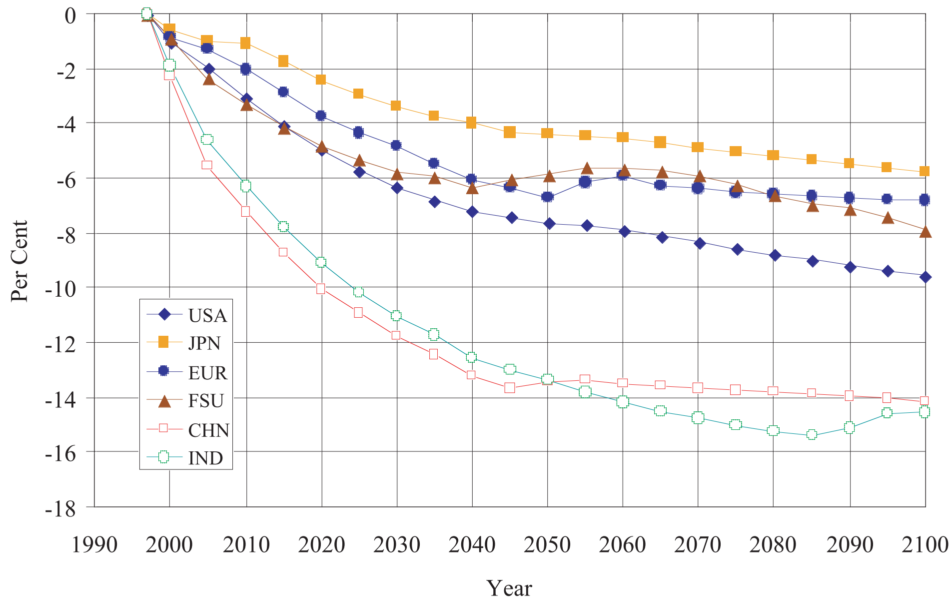

Figure 7. Differences in GNP with emissions restrictions policy in solutions with sector specific labor and rigid wages compared to solutions with flexible labor and flexible wages.

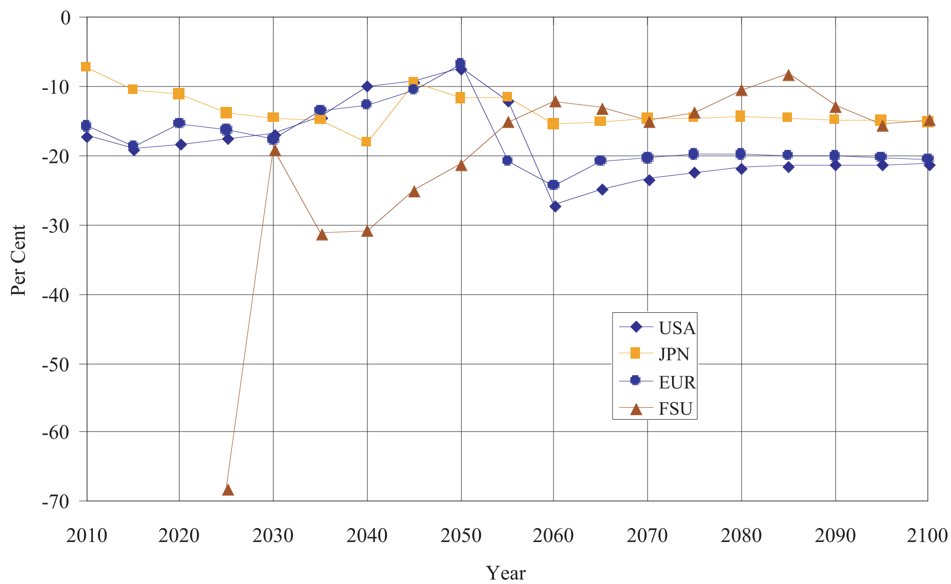

Figure 8. Differences in carbon prices due to policy case with and without sector specific labor and rigid wages.

6. POLICY TO REDUCE THE ECONOMIC IMPACT OF EMISSIONS RESTRICTIONS

The preceding analysis indicates that there would be a real, direct depressing effect from the imposition of emissions restrictions. The EPPA model, as pointed out above, is not ideal for the measurement of the effects, as it has a built-in growth assumption that overrides those negative effects, but it shows the impact by generating unemployment and slowing the effective growth rates. The effect would not “wreck the economy,” as the Bush speech implied. Nonetheless the effect is quite discernible. So it is natural to take the next step of asking whether the negative effects could be offset.

Overall monetary and fiscal policies are not right for the task, as the source of the problem is not a cyclical recession, but a structural change in the economy—the imposition of the emissions restrictions. Those restrictions force up the price of fossil fuels, so one might think of subsidies to the use of those fuels. That would obviously be incorrect as such subsidies would stimulate their use, whereas the objective is to reduce their use. Similarly, subsidies to reduce the prices of commodities particularly affected by the emissions restrictions would be incorrect, as the objective is to shift demands away from those commodities.

The policy investigated here is a subsidy for the use of labor, to reduce the unemployment created by the emissions restrictions policy, when there are both sector specific labor and rigid wages. Subsidies are provided in two ways. First, the amount of the subsidy is generated endogenously, so as to maintain employment at the levels attained in the Reference Solution, without emissions restrictions. The second subsidy is a stipulated amount. The endogenous subsidies are spread across all sectors, although they are concentrated in the energy sectors, and range from 3 to 25% of labor costs. The wage subsidies are 15% for coal, 10% for oil and gas and at 5% for the rest of sectors.

The results for GNP when there are emissions restrictions and labor market imperfections, with the endogenous subsidies, are shown in **Figure 9**, compared to the case when the emission restriction policy is applied without subsidies. The labor subsidies actually result in small increases in GDP, while emissions remain unchanged, because of the policy restrictions, and there is a small increase in the carbon price.

Examples of the effects of a particular exogenous specification of labor subsidies, with the emissions policy restrictions, are shown in **Figure 10**. There are two clear benefits from these subsidies. First, there are more substantial improvements in GNP, as compared to the situation in which emissions restrictions policies and labor market imperfections are offset by endogenously determined subsidies. Second, the subsidy completely eliminates unemployment resulting from the emissions restriction policy.

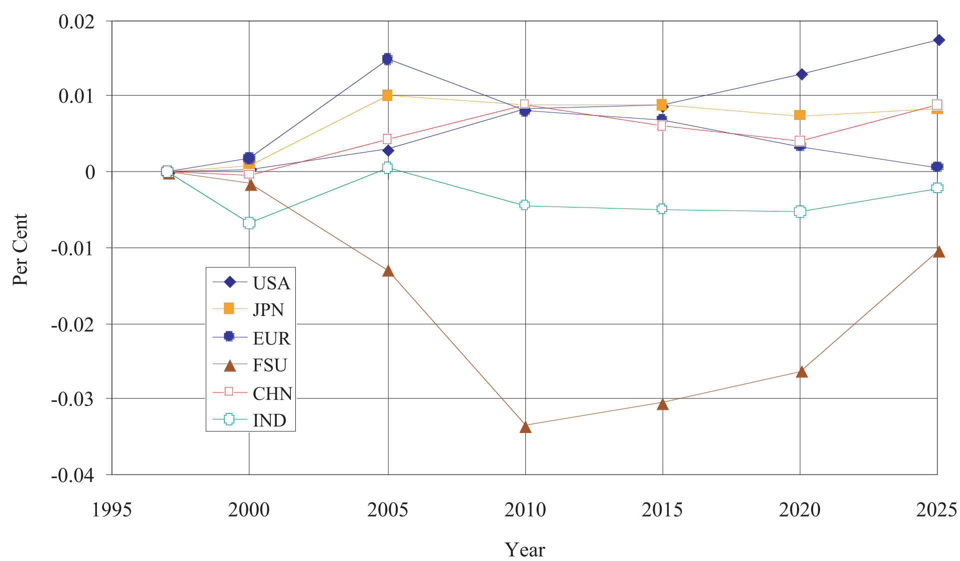

Figure 9. GNP differences with sectorally specific labor, rigid wages and with emissions restrictions without and with endogenous subsidies.

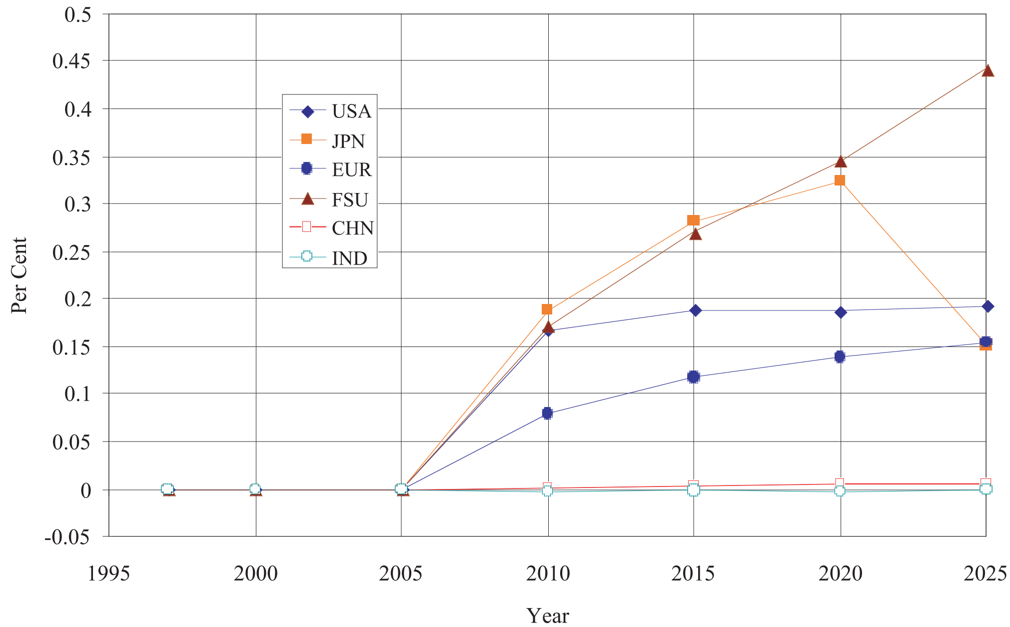

Figure 10. GNP differences with sectorally specific labor, rigid wages and with emissions restrictions with and without stipulated subsidies.

The explanation for the increases in GNP and in employment is straightforward: the labor subsidies induce a somewhat more intensive use of labor, resulting in increased output, as well as increased employment. These improvements can be explained as the consequence of imposing a third "imperfection," when there are already two others: the emissions restrictions and the labor market imperfections.

7. CONCLUSIONS

The concern is correct that emissions restrictions policies would impose overall reductions in GNP and result in an increase in unemployment rates, if not somehow offset. The effects derived from the model experiments described above are relatively small, but noticeable. Yet, as with other modeling results of this type, it is difficult to assess whether the estimates provided are too large or too small or just right. We do not have the luxury of detailed data and econometric estimation. And the numeric assumptions employed, with respect to the sectoral specificity of labor and the rigidity of wages, while plausible, cannot be verified empirically.

Yet the calculations make the point that the negative economic effects of emissions cannot be brushed off, particularly with respect to the politically very sensitive unemployment consequences. However, the point is also made that if the one type of interference with the markets is imposed, in this case the imposition of emissions restrictions, an offsetting policy, e.g. wage subsidies, can ameliorate, and possibly eliminate the negative effects and should be a part of the overall package.

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