FONDAZIONE ENI ENRICO MATTEI

NOTA DI LAVORO

44.2012

Beyond GDP: Modelling Labour Supply as a 'Free Time' Trade-off in a Multiregional Optimal Growth Model

By **Valentina Bosetti**, FEEM, Fondazione Eni Enrico Mattei, and CMCC Centro Euro-Mediterraneo per i Cambiamenti Climatici, Italy

Frédéric Ghersi, CIRED – Centre International de Recherche sur l'Environnement et le Développement, Italy

Climate Change and Sustainable Development Series
Editor: Carlo Carraro

Beyond GDP: Modelling Labour Supply as a 'Free Time' Trade-off in a Multiregional Optimal Growth Model

By Valentina Bosetti, FEEM, Fondazione Eni Enrico Mattei, and CMCC Centro Euro-Mediterraneo per i Cambiamenti Climatici, Italy
Frédéric Ghersi, CIRED – Centre International de Recherche sur l'Environnement et le Développement, Italy

Summary

In this paper we develop the standard utility function of a Ramsey-type optimal growth model to account for a 'market-time' vs. 'free-time' trade-off. To do so, we introduce a free-time preference coefficient that measures the utility gained by deviating from a maximum labour supply defined as the combination of a 95% labour force participation rate for the 20 to 69 year-old population, and 3000 annual working hours (50 effective 60-hour weeks). We calibrate this free-time preference coefficient for 12 world regions on statistical and projected data from the United Nations, the International Labour Organisation and the OECD. We illustrate a prospective use of this modelling development by comparing the consequences of convergence of the free-time preference coefficients of all world regions to the contrasted Western European vs. United States value. Over the 21st century, compared to a business-as-usual trajectory defined by maintained regional disparities in free time preference, convergence to US free time preference induces a 0.3% decrease in global discounted labour market time, but a 4.2% increase in discounted global GDP sustained by a 2.5% increase in primary energy consumption that translates into a 1.7% increase in cumulated CO2-equivalent emissions; convergence to Western European free time preference decreases labour market time by 13.8%, GDP by 11.7%, primary energy consumption by 10.7% and cumulated CO2-equivalent emissions by 9.1%.

Keywords: Ramsey Growth Model, Endogenous Labour Supply. Utility of Leisure, Beyond GDP Welfare Valuation

JEL Classification: C0, O4

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007/2013) under the grant agreement n° 244766 – PASHMINA and from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013) ERC grant agreement n°240895 – project ICARUS "Innovation for Climate Change Mitigation: a Study of energy R&D, its Uncertain Effectiveness and Spillovers".

Address for correspondence:

Valentina Bosetti
Fondazione Eni Enrico Mattei
Corso Magenta 63
20123 Milano
Italy
Phone: +39 02.520.36948
Fax: +39 02.520.36946
E-mail: valentina.bosetti@feem.it

Beyond GDP: modelling labour supply as a ‘free time’ trade-off in a multiregional optimal growth model

Valentina Bosetti[1] and Frédéric Ghersi[2]

[1] FEEM - Fondazione Eni Enrico Mattei, Corso Magenta 63, 20123 Milano, Italy and CMCC - Centro Euro-Mediterraneo per i Cambiamenti Climatici. Corresponding Author. E-mail: valentina.bosetti@feem.it, Phone: +39 02.520.36948, Fax: +39 02.520.36946.

[2] CIRED – Centre International de Recherche sur l’Environnement et le Développement, 45 bis, avenue de la Belle Gabrielle, 94736 Nogent sur Marne CEDEX, France

Abstract

In this paper we develop the standard utility function of a Ramsey-type optimal growth model to account for a ‘market-time’ *vs.* ‘free-time’ trade-off. To do so, we introduce a free-time preference coefficient that measures the utility gained by deviating from a maximum labour supply defined as the combination of a 95% labour force participation rate for the 20 to 69 year-old population, and 3000 annual working hours (50 effective 60-hour weeks). We calibrate this free-time preference coefficient for 12 world regions on statistical and projected data from the United Nations, the International Labour Organisation and the OECD. We illustrate a prospective use of this modelling development by comparing the consequences of convergence of the free-time preference coefficients of all world regions to the contrasted Western European *vs.* United States value. Over the 21st century, compared to a business-as-usual trajectory defined by maintained regional disparities in free time preference, convergence to US free time preference induces a 0.3% decrease in global discounted labour market time, but a 4.2% increase in discounted global GDP sustained by a 2.5% increase in primary energy consumption that translates into a 1.7% increase in cumulated CO2-equivalent emissions; convergence to Western European free time preference decreases labour market time by 13.8%, GDP by 11.7%, primary energy consumption by 10.7% and cumulated CO2-equivalent emissions by 9.1%.

Keywords

Ramsey growth model; endogenous labour supply; utility of leisure; beyond GDP welfare valuation.

Acknowledgments

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007/2013) under the grant agreement n° 244766 – PASHMINA and from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013) ERC grant agreement n°240895 – project ICARUS "Innovation for Climate Change Mitigation: a Study of energy R&D, its Uncertain Effectiveness and Spillovers".

Introduction

The growing dissatisfaction with GDP and consumption as the prominent indicators of development and hence the main objective of policymakers, has led us to study the implications of an augmented definition of welfare that endogenises the free time *vs.* labour market time choice in an optimal growth model.

The literature on the trade-off between the free and market use of time is for some of it more than 50 years old (for a recent elegant survey *cf.* Weiss, 2009). It is fundamentally concerned with understanding the divergence in working hours in European countries and the United States. In recent years, Prescott (2004) concentrated on the effect of differentials in labour taxes, while Alesina *et al.* (2006) pointed to the effect of unionisation of European labour forces. Both papers do not deal with the consequences on either productivity and innovation or welfare of these two different paradigms, although Alesina *et al.* (2006) hint to studies showing larger reported happiness in countries where the number of vacation days is greater.

A different strand of literature looks at the impact of time allocation on productivity and on economic cycles. This vast literature spans from microeconomic studies on health, flexible working hours and economic productivity, to business cycle analyses and the analysis of the household *versus* market work conundrum. Blanchard (2004) offers a synthetic view of its conclusions based on a discussion of the differential in market working hours on either side of the Atlantic and the increase in labour productivity in European countries, in the context of a broader assessment of the evolution of European economies. He concludes that, although Europe has caught up on the United States in productivity terms over the last thirty years, contrary to the United States it has used some of this progress to increase leisure rather than income.

Finally, an overarching literature is that looking into new measures of growth, going beyond pure GDP measures and accounting for other crucial indicators of life satisfaction and happiness. Initiated by Sen in the late 60's (*cf.* the milestone Sen, 1976), this literature has had important contributions on the specific theme of leisure, as by Nordhaus and Tobin (1973); the 'beyond GDP' report commissioned by the French government has recently offered an extensive survey and revitalisation of this debate (Stiglitz *et al.*, 2009). From its angle the key issue is how to properly account for the leisure/household/work trade-off and what metrics to use: diary data and surveys on the use of time distinguish between time spent on the market, on providing and managing the household, in leisure activities and for basic needs. For the largest part, though, data on paid working hours alone are available. In addition, even when data on non-paid activities are available, cultural differences complicate the aggregation of detailed time uses into operative categories—*e.g.* caring for children can alternatively be considered as management of the household or sheer leisure time.

We build on this literature, while purposely limiting our interpretation of it: our ambition is to provide broad assessments of paradigm shifts to alternate societal futures characterised by rebalanced time allocation choices between the two aggregates of labour market time and 'free time'; we insist on the intrinsic value of 'free time' without disambiguating between its social (welfare value of sheer leisure, of a gift economy, *etc.*) *vs.* microeconomic interpretations (household production function, educational investment justified by dynastic solidarity, *etc.*).

We start with a section exploring the analytics of our augmented Ramsey model, followed by a section discussing the data used for the calibration of a numerical model. A third section presents the particulars of our numerical model, and the simulation runs for contrasted convergence assumptions regarding the central free time valuation coefficient introduced in the model; from it we derive some concluding remarks.

I. The model

The microeconomic rationale of our market labour supply model is based on Prescott (2004), which itself traces back to Kydland and Prescott (1982). The 'real business cycle' motivation of the latter paper is much toned down in the former one though—which suits our purpose well: we do not aim at explaining short term fluctuations around a fundamental trend. As already developed, we also abstract from addressing the complex heterogeneity of time spent off the labour market, despite the caveats expressed as early as Gronau (1977), nor do we try to build on Becker's household production model (Becker, 1965) and the subsequent literature.[1] We also differ from Prescott (2004) and Alesina *et al.* (2006) inasmuch as we do not aim at identifying why free time preferences vary across societies—without settling between Alesina *et al.*'s case for unionisation or that of Prescott for fiscal pressure, we simply consider that both putative causes can more fundamentally be interpreted as the expressions of collective preferences. What we rather do is adopt their functional form, firmly rooted in microeconomic reasoning, and use macroeconomic data to project its impact on future development trajectories. Thus, adapting Prescott (2004) we assume that the objective function of the aggregate agent of some economy over T time periods is

$$U = \sum_{t=1}^{T} R_t \left[u_t(C_t) + \alpha_t v_t(\phi_t) \right], \quad (2)$$

with R_t a discount factor (social time preference factor); C_t total consumption; α_t a 'free time' preference coefficient; ϕ_t market labour supply, and u_t and v_t the functions through which the utility impacts of C_t and ϕ_t are measured—quite obviously $u_t' > 0$ and $v_t' < 0$. The standard utility source consumption C_t is thus augmented by a negative function of the time devoted to the labour market, ϕ_t. The trade-off is made explicit by formulating the budget constraint of the aggregate agent, stating that production Y_t is equal to (or greater than, but it is obviously optimal to systematically saturate the constraint) the sum of investment I_t and consumption C_t:

$$Y_t = I_t + C_t \quad (3)$$

then by considering that the succession of Y_t derives itself from a production function combining capital stock K_t and labour force L_t:

$$Y_t = A_t F(K_t, \phi_t L_t) \quad (4)$$

with A_t a calibrated total factor productivity coefficient. Compared to the standard neoclassical production function ϕ_t is now multiplying labour endowment L_t, to embody the new trade-off possibility. Note that we maintain the exogeneity of total factor productivity A_t, and leave to further research an explicit modelling of the complex connections between A_t and ϕ_t.[2] As a consequence Y_t, and thus, through equation (3), C_t are now functions of ϕ_t. K_t is itself connected to I_t through its dynamics:

[1] For a review of labour supply models *cf.* Blundell and Macurdy (1999).

[2] Following the lines opened by Blanchard (2004), as evoked in our introduction.

$$K_{t+1} = (1-\delta)K_t + I_t \tag{5}$$

The intertemporal maximisation programme can thus be collapsed in:

$$\underset{C_t,\phi_t}{Max}\sum_{t=1}^{T} R_t \left(u_t(C_t)+\alpha_t\, v_t(\phi_t)\right) \tag{6}$$

subject to:

$$K_{t+1} = (1-\delta)K_t + A_t\, F(K_t, \phi_t L_t) - C_t \tag{7}$$

The corresponding Bellman value function (a recursive re-writing of the optimisation problem viewed from any time *t*) is

$$V_t(K_t) = \underset{C_t,\phi_t}{Max}\; u_t(C_t)+\alpha_t\, v_t(\phi_t) + \frac{R_{t+1}}{R_t} V_{t+1}(K_{t+1}) \tag{8}$$

The first order conditions on C_t and ϕ_t, after injection of the partial derivatives of K_{t+1} obtained from equation (7), read:

$$\frac{\partial u_t}{\partial C_t} - \frac{R_{t+1}}{R_t}\frac{\partial V_{t+1}}{\partial K_{t+1}} = 0 \tag{9}$$

and

$$\alpha_t \frac{\partial v_t}{\partial \phi_t} + \frac{R_{t+1}}{R_t}\frac{\partial V_{t+1}}{\partial K_{t+1}} A_t \frac{\partial F}{\partial \phi_t} = 0 \tag{10}$$

while the envelope condition (K_t derivative of V_t yielded by equation (8)) of the programme is:

$$\frac{\partial V_t}{\partial K_t} = \frac{R_{t+1}}{R_t}\frac{\partial V_{t+1}}{\partial K_{t+1}}\left(1-\delta + A_t \frac{\partial F}{\partial K_t}\right) \tag{11}$$

Equations (9) and (10) provide expressions for the derivatives of *V* at time *t+1*, which also hold at time *t*; injecting them in the envelope condition yields the two Euler conditions:

$$\frac{\partial u_{t-1}}{\partial C_{t-1}} = \frac{R_t}{R_{t-1}}\left(1-\delta + A_t \frac{\partial F}{\partial K_t}\right)\frac{\partial u_t}{\partial C_t} \tag{12}$$

and

$$\frac{\partial v_{t-1}}{\partial \phi_{t-1}} = \frac{R_t}{R_{t-1}}\frac{\alpha_t}{\alpha_{t-1}}\frac{A_{t-1}\dfrac{\partial F}{\partial \phi_{t-1}}}{A_t \dfrac{\partial F}{\partial \phi_t}}\left(1-\delta + A_t \frac{\partial F}{\partial K_t}\right)\frac{\partial v_t}{\partial \phi_t} \tag{13}$$

The question is then: can the recursions hope to be solved? Under the standard constraint of a positive I_T and disregarding any transversal condition on K_{T+1}, C_T is obviously equal to $A_T\, F(K_T,\ \phi_T\, L_T)$: it is optimal to consume all of the last period's production. Provided the u_t, v_t and *F* functions are 'tractable' enough, substituting $A_T\, F(K_T,\ \phi_T\, L_T)$ for C_T in the first order conditions of V_T, allows computing ϕ_T as a function of K_T, L_T, A_T, α_T and R_T. By recursion of equation (7) and the Euler equations (12) and (13) the optimal trajectories of *C* and ϕ can hope to be inferred, at least numerically—even for the simplest functional forms (*e.g.* *F* a Cobb-Douglas, *u* and *v* logarithmic functions) the recursions, consisting in complex polynomial expressions, are not analytically solvable. They can however be used, for calibration purposes, to derive an analytical expression of the central α

coefficient. Indeed, substituting $A_T\,F(K_T,\ \phi_T\ L_T)$ for C_T in V_T allows deriving, through the first order condition on ϕ_T, an expression for α_T:

$$\alpha_T = A_T \frac{\dfrac{\partial F}{\partial \phi_T}}{-\dfrac{\partial v_T}{\partial \phi_T}} \frac{\partial u_T}{\partial C_T} \tag{14}$$

As injecting (12) into (13) yields

$$\alpha_{t-1} = \frac{A_{t-1}}{A_t} \frac{\dfrac{\partial F}{\partial \phi_{t-1}}}{\dfrac{\partial F}{\partial \phi_t}} \frac{\dfrac{\partial u_{t-1}}{\partial C_{t-1}}}{\dfrac{\partial u_t}{\partial C_t}} \frac{\dfrac{\partial v_t}{\partial \phi_t}}{\dfrac{\partial v_{t-1}}{\partial \phi_{t-1}}} \alpha_t\,, \tag{15}$$

the recursion on α is easily solved as:

$$\forall t \in [1,T]\ \ \alpha_t = A_t \frac{\dfrac{\partial F}{\partial \phi_t}}{-\dfrac{\partial v_t}{\partial \phi_t}} \frac{\partial u_t}{\partial C_t} \tag{16}$$

Rearranging the expression by shifting the ϕ-derivative of v on the left-hand side makes interpretation clearer: α must be calibrated in such a way that the marginal utility of extended 'free time' $-\alpha_t \dfrac{\partial v_t}{\partial \phi_t}$ equates the instantaneous marginal utility of extended working hours (which derives from consuming the product of such hours) $-A_t \dfrac{\partial F}{\partial \phi_t}\dfrac{\partial u_t}{\partial C_t}$. It might come as a surprise that the dynamic impact of production on capital accumulation does not seem to play any role; but at the optimum, where α is calibrated, the marginal utility of consumption is by definition equal to that of investment. Equation (16) could indeed be inferred from the static programme of maximising $u_t + \alpha_t\, v_t$ only: the calibration process assumes that the intertemporal trade-off between current and future consumption is already settled, and holds.

II. The data

Following a literature tracing back to Lucas and Rapping (1969), we acknowledge that market labour supply results from the combination of three distinct determinants: the sheer dynamics of population growth, which determines the population of working age; the participation rate, which measures the share of the population of working age that is indeed participating to the labour market; the average amount of time spent at work, measured *e.g.* in annual working hours—a statistics that indeed widely differs from one country to another. Like most of the available economic literature, we do not try to endogenise the first of these dimensions, *i.e.* population growth *per se*, and rather focus on the two other determinants. To our knowledge this still constitutes quite a development for the state-of-the-art of large numerical optimisation models. The data used are of two main sorts:

- Sheer demographic counts are used to develop projections of the total and active population of 12 macro regions.[3] Both the Economically Active Population, Estimates and Projections (EAPEP) and the International Labour Organisation (ILO) were used and processed.
- Data on working times were then collected from the ILO and the OECD to provide estimates of annual working hours. Where estimates were not available assumptions had to be made to come up with a complete set of regional working time estimates.

The demographics of the total and active population are obtained from a combination of data from the International Labour Organisation (ILO), and the United Nations Population Division (UNPD). From ILO we exploit the Economically Active Population Estimates and Projections (EAPEP) database,[4] which provides a comprehensive set of economically active and indeed total population estimates and projections for 191 countries and 13 age groups (0 to 9 then by 5-year age groups up to 65 and older), every year from 1980 to 2020. From UNPD we use the medium variant of total population estimates and projections for 196 countries by five-year age groups (from the 0 to 4-year old to the beyond 100), from 1950 to 2050 in 5-year steps.

We combine and process the data in the following way. First, we aggregate the EAPEP into the 12 regions we use in the numerically calibrated model, and cross total and active population counts to compute activity rates by age group from 1980 to 2020. We then extrapolate the rates from 2008-2020 (*i.e.* those resulting from the projections of ILO rather than reassessed on available statistics) to 2050, by resorting to the same logarithmic functions that are used in ILO's own methodology (ILO, 2009).[5] Next, we apply the ILO activity rates of 2005, 2010, 2015 and 2020, and the rates resulting from our extrapolation to 2025, 2030, …, 2050, to the total counts by age group of the UNPD at the corresponding year, to derive active population counts at these years. Note that EAPEP provides counts of both the active and total population up to 2020 that we could have used without further manipulation, but we chose to retain UNPD figures for reference purposes.

Beyond 2050, for lack of better hypotheses, (*i*) we reproduce the growth rates of the total population counts from UNDP longer term projections, and (*ii*) we stabilise the activity rates at their 2050 values. The total and active population counts deriving from these treatments and assumptions are reported in annex.

It must be underlined that the demographics of intertemporal optimisation models (*e.g.* the RICE model of Nordhaus and Yang, 1996) is generally limited to total population, used as a proxy of the available labour force. After proper calibration of the production functions this only amounts to assume that labour endowment grows at the same pace as total population. But the collected data (*cf.* Annex) contradicts this assumption: it reveals growth rate differentials of up to 5 percentage points, in some instances indeed growth rates of opposed signs—because of inertia the decrease of active population lags behind that of total population. The issue is not to be exaggerated, as most models resort to exogenous regional total factor productivity improvements that are calibrated to shape trajectories on exogenous growth scenarios, typically those of international institutions—such as those

[3] These are purposely defined as the pre-existing macro regions of the WITCH model (Bosetti *et al.*, 2006), which provides the numerical framework of our section 3 implementation.

[4] *Cf.* http://laborsta.ilo.org/applv8/data/EAPEP/eapep_E.html. The page provides a link to a thorough methodological description (ILO, 2009).

[5] The precision of the fit on the 13 data years (2008 to 2020) is high in most cases: 95 of the 132 R^2 determination coefficients (11 active age groups × 12 regions) are above 0.9.

of the IPCC Special Report on Emission Scenarios or SRES (IPCC, 2000). A higher degree of demographic detail is however necessary to our labour supply modelling endeavour.

The second ingredient necessary to project labour supply potentials is working time statistics.[6] Although some national surveys on the use of time and diaries exist, a comprehensive and consistent 'pseudo-data' source comparable to EAPEP with global coverage does not. OECD provides estimates of annual working hours for its 34 members and the Russian Federation,[7] which we directly used. Then ILO has a database of 4 distinct types of weekly hours[8] for a large number of countries from 1969 to 2008, but with quite large gaps in both geographical and time coverage.[9] Considering the scarcity of this data we focus on our twelve macro regions and the 2005 base year. We then combine the two sources to produce an estimate of annual working hours for each region—an average of member country estimates weighted by the active population counts of each country.

The OECD estimates are retained for regions that are mainly composed of OECD countries—5 out of 12. Then ILO data is used to derive estimates for the non OECD regions, with the difficulty that the weekly hours have to be converted to annual ones. To guide this conversion we systematically explored the ratio between OECD estimates and ILO ones, theoretically corresponding to the average number of weeks annually worked, but to little benefit: results suggest some discrepancies between the 2 sets of data (*cf.* Table 1); from 2004 to 2008 (the 5 most recent years available), the ILO and OECD data for Canada, Estonia, Greece, Italy, New Zealand and the United States are irreconcilable (annually worked weeks resulting from the combination of the two datasets are over 50), without any possibility to discriminate between the reliability of each source.

[6] Throughout this section, for reference purposes to the underlying statistical data, we fall back on the ambiguous practice of qualifying as 'working' the time spent on activities paid for by market transactions, thereby misleadingly implying that any time other than monetised labour is non-working time. The statistical object is however precisely that which we need measurement of, *i.e.* market labour supply.

[7] *Cf.* the OECD statistics portal at http://stats.oecd.org.

[8] "Hours actually worked", "hours paid for", "hours usually worked", "normal hours of work". For the distinction between the 4 statistics *cf.* http://laborsta.ilo.org/applv8/data/c4e.html.

[9] *Cf.* the ILO statistics portal at http://laborsta.ilo.org.

Country	2004	2005	2006	2007	2008
Australia	49.87	49.80	49.73	49.55	49.80
Austria	46.46	47.33	47.24	47.12	47.50
Canada	56.71	56.26	56.24	56.91	56.82
Estonia	57.35	57.77	57.64	57.59	57.46
Finland	47.87	47.53	47.60	47.53	47.45
Greece	50.54	50.75	53.30	53.02	-
Iceland	45.71	45.19	45.21	45.63	45.63
Ireland	45.08	44.82	44.86	44.81	44.35
Israel	49.78	49.67	49.35	49.50	49.69
Italy	52.62	52.11	52.15	52.20	52.22
Mexico	42.50	-	-	-	-
New Zealand	52.04	52.01	51.94	51.86	51.52
Poland	49.82	50.23	49.63	49.52	-
Portugal	49.80	49.08	49.22	49.06	49.72
Slovenia	-	46.90	41.83	47.43	-
Spain	48.00	47.93	47.30	47.16	47.52
Switzerland	46.34	46.31	45.90	45.51	45.72
United States	51.06	51.56	52.97	53.79	49.95

Table 1 **Ratio of OECD annual working hours to ILO hours actually worked *per* week, supposedly: number of weeks worked *per* year**

Source: authors' computation on OECD and ILO data. OECD countries figure only if OECD and ILO data can be compared for one of the 5 years reported.

For lack of a better hypothesis, and after close scrutiny of the data in need of a conversion factor—which covers sub-Saharan Africa (SSA), the Middle-East and North Africa (MENA), East and South Asia (EASIA and SASIA), and the Latin and Caribbean America (LACA) regions—, we apply the average number of working weeks computed for Mexico over the 11 years where it is available, namely 42.70 weeks. Although this is a quite low number of weeks, comparable to that of the least working countries only,[10] it is still slightly above the estimates for Turkey[11]—and does simply deliver plausible results when systematically applied to the countries in need of such an assumption (45 countries): the 7 non-OECD estimates end up within the range of the original OECD data, and indeed MENA is higher than any of them (Table 2), 38% above the lowest estimate, that of Western Europe (WEURO). Data is too scarce for the SSA and MENA regions though (*cf.* their 'labour force data coverage' indicator), and it is to hope that new statistics will be issued to allow reinforcing the reliability of these constructions.

[10] France in 1995 and 1996 (most recent available years), surprisingly enough Japan from 1999 to 2002 (*id.*), Norway from 1986 to 1995 (*id.*), Sweden from 1978 to 1994 (*id.*).

[11] An average of 40.85 working weeks between 1988 and 1999.

Macro region[12]	Labour force data coverage	Annual working hours
USA	100%	1 800
WEURO	100%	1 614
EEURO	66%	1 967
KOSAU	66%	2 167
CAJAZ	100%	1 768
TE	62%	1 943
MENA	36%	2 221
SSA	33%	1 956
SASIA	88%	2 002
CHINA	99%	2 041
EASIA	81%	1 914
LACA	94%	1 854

Table 2 **Annual working hours of 12 macro regions, 2005**

Source: OECD, ILO, authors' computation (*cf.* above). 'Labour force data coverage' is the ratio of the active population of member countries with some working hour statistic (OECD or ILO) to total regional active population.

To conclude this subsection, let us underline that our repeated use of the 'working time' and 'working hours' expressions is simply mirroring statistical practice, whereas the time aggregated in such series is consistently that spent on activities paid for by market transactions, excluding any type of unpaid work. We hesitated on introducing new notations to clarify this ambiguity, but eventually settled against it for the sake of clarity, considering the widespread use of the statistical series under the conventional though somewhat misleading appellations.

III. Numerical implementation

We now turn to a numerical implementation of the model described in section 1, with a view to illustrate the impact on GDP and labour market time of prospective shifts in 'free time' valuation. To do so we mobilise WITCH (Bosetti *et al.*, 2006), a climate-energy-economy model designed to assist in the study of the long-term environmental and socio-economic processes. WITCH was developed to provide information on the optimal responses of world economies to climate damages and to identify the impacts of climate policy on global and regional economic systems. It has also been used to study the mid and long-term dynamics of innovation in energy technologies. A thorough description and a list of related papers and applications are available at www.feem-web.it/witch.

[12] The retained macro regions match those of the WITCH model. Detailed composition of WITCH regions is available at http://www.witchmodel.org/.

III.1. An extended WITCH model

Section 1's analytical framework was laid out with a view to be compatible with WITCH's specifications. Specifying the hitherto nondescript *F*, *u* and *v* functions in the case of a modified WITCH model will allow calibrating α coefficients on pre-existing baseline trajectories of the model, a necessary first step to our numerical implementation.

First, the production function of each of the model's 12 regions[13] combines a Cobb-Douglas aggregate of capital stock K_t and labour force L_t, and energy services ES_t, in a constant elasticity of substitution (CES) aggregate:

$$Y_t = A_t \left(a \left(K_t^{\beta} \phi_t^{1-\beta} L_t^{1-\beta} \right)^{\rho} + (1-a) ES_t^{\rho} \right)^{1/\rho} \tag{17}$$

with unchanged A_t, K_t, L_t and ϕ_t notations, a a calibrated CES coefficient, β the cost share of capital in the *KL* aggregate, and ρ the CES coefficient related to the substitution elasticity of the KL and ES aggregates. Note that compared to the unmodified WITCH model (*cf.* Bosetti *et al.*, 2006) ϕ_t is now multiplying labour supply L_t, following section 1. Note also that this specification departs from our analytical exploration, inasmuch as output is not a function of *K*, *L* and ϕ only, but also of *ES*. Although accounting for the endogeneity of *ES* is a hard nut to crack in analytical terms, this does not invalidate our calibration of the regional α coefficients under equation (16): similar to the consumption/savings trade-off, the arbitrage in favour of energy expenses is already accounted for in the pre-existing optimal trajectories on which we will calibrate α. A further subsection will confirm this.

Second, in WITCH the utility derived from consumption is of the form

$$u_t(C_t) = N_t \ln\left(\frac{C_t}{N_t} \right), \tag{18}$$

i.e. a standard log-linear utility function of *per capita* consumption, considering a total population count *N*.

Third, for this first numerical implementation we will follow Prescott (2004) again in assuming that

$$v_t(\phi_t) = L_t \ln\left(\Phi_t - \phi_t \right), \tag{19}$$

where Φ_t is an upper bound to market labour supply (the object of our next subsection). The standard utility source, *i.e.* the product of total population N_t and of the logarithm of *per capita* consumption, is thus augmented by the product of active population L_t and of the logarithm of the time that this population could devote to the labour market, but is not, $\Phi_t - \phi_t$. Note that assuming both u_t and v_t a logarithmic form amounts to assuming a Cobb Douglas substitutability between consumption and free time, a standard assumption we will not further comment upon.[14]

Under these specifications, and retaining the simplifying assumption that energy services ES_t are exogenous, the derivatives that define the calibration of α following equation (16) read:

[13] For the sake of readability we dropped the regional indexes of all of WITCH's equations.

[14] Although we share this assumption with most of the existing literature, we readily acknowledge it calls for sensitivity analysis—at least of a numerical nature, considering the difficulty of drawing analytical conclusions from more complex models. We reserve such analysis to further research.

$$\frac{\partial F}{\partial \phi_t} = \frac{1-\beta}{\phi_t}\left(\frac{Y_t}{A_t} - \left(\frac{Y_t}{A_t}\right)^{1-\rho} (1-a)\, ES_t^{\rho} \right) \tag{20}$$

$$\frac{\partial u_t}{\partial C_t} = \frac{N_t}{C_t} \tag{21}$$

and

$$\frac{\partial v_t}{\partial \phi_t} = -\frac{L_t}{\Phi_t - \phi_t} \tag{22}$$

Thus the α trajectory compatible with any consistent set of A, Φ, L, Y, ES and N trajectories, considering the β, ρ and a parameters and normalising ϕ to 1:

$$\forall t \in [1,T] \;\; \alpha_t = A_t \frac{\Phi_t - \phi_t}{L_t} \frac{1-\beta}{\phi_t}\left(\frac{Y_t}{A_t} - \left(\frac{Y_t}{A_t}\right)^{1-\rho} (1-a)\, ES_t^{\rho} \right)\frac{N_t}{C_t} \tag{23}$$

III.2. Estimating potential labour supply

Prescott's assumption about Φ focuses on hours worked *per* week, and sets an upper bound of 100 hours common to all economies. Our approach differs inasmuch as, on top of considering a corresponding upper bound to annual working hours (AWH), we do extend the possible labour supply adjustments to an increase in the labour force participation rate (LFPR).

The leeway assumed on the LFPR is measured by the gap between the observed participation to the labour force, and a potential defined by 95% LFPR for all age groups between 20 and 69, the contribution of all other groups being kept constant. This is arguably a maximum participation rate for the population between 20 and 69. Among others it assumes that any difference between the LFPRs of men and women has all but disappeared, which accounts for the higher potential increase of supply in the MENA zone, where women currently have low LFPRs (Table 3); it also assumes, for most regions, postponed retirement decisions compared to current practice—an arguably benign assumption when considering the prospective nature of our modelling, and the expected increases in life expectancy.

Year	USA	WEURO	EEURO	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LACA
2005	1.24	1.34	1.41	1.38	1.27	1.36	1.56	1.18	1.41	1.13	1.21	1.29
2010	1.25	1.31	1.43	1.36	1.27	1.35	1.57	1.18	1.41	1.15	1.22	1.28
2015	1.26	1.31	1.46	1.36	1.28	1.37	1.59	1.17	1.42	1.17	1.22	1.27
2020	1.27	1.32	1.47	1.36	1.26	1.40	1.61	1.17	1.43	1.20	1.23	1.28
2025	1.27	1.33	1.47	1.37	1.26	1.40	1.62	1.17	1.43	1.21	1.24	1.28
2030	1.27	1.35	1.48	1.37	1.27	1.41	1.64	1.16	1.44	1.24	1.24	1.29
2035	1.26	1.35	1.53	1.37	1.28	1.42	1.66	1.16	1.45	1.25	1.24	1.29
2040	1.25	1.33	1.58	1.37	1.29	1.44	1.68	1.16	1.46	1.24	1.25	1.29
2045	1.25	1.33	1.61	1.36	1.28	1.46	1.70	1.16	1.47	1.24	1.25	1.30
2050	1.26	1.32	1.60	1.37	1.27	1.47	1.72	1.16	1.48	1.25	1.25	1.30

Table 3 **Ratio of maximum to observed labour supply based on LFPR potential, 12 WITCH regions**

Source: authors' computation on an exogenous assumption of maximum LFPR and projections of active population derived from OECD and ILO.

Next, the potential development of AWH is based on the simple assumption of a maximum 60-hour week extending to 50 weeks in the year,[15] for a total of 3,000 hours worked annually. Regional potentials are in this regard straightforwardly derived from their respective AWH (Table 4). Note that this specification is making little of the many current regulations on labour time around the globe, as indeed did that of a retirement postponed to 69. These are considered as mere expressions of regional preferences—including, quite indirectly and in a more polemical way, of preferences for the nature and degree of democracy in the decision making process that produced them—, bound to adapt to the time allocation choices induced by our specification (an argument developed by *e.g.* Zilibotti, 2007).

WITCH region	Annual working hours	Ratio of 3,000 annual hours to annual working hours
USA	1,800	1.67
WEURO	1,614	1.86
EEURO	1,967	1.53
KOSAU	2,167	1.38
CAJAZ	1,768	1.70
TE	1,943	1.54
MENA	2,221	1.35
SSA	1,956	1.53
SASIA	2,002	1.50
CHINA	2,041	1.47
EASIA	1,914	1.57
LACA	1,854	1.62

Table 4 **Ratio of maximum to observed labour supply based on AWH potential, 12 WITCH regions**

Source: OECD and ILO (*cf.* Table 2 above), authors' computation on an exogenous 3,000 maximum AWH.

[15] Note that the 2 weeks left out include national holidays.

Crossing the LFPR and AWH potentials, potential labour force developments in 2050 range from a factor 1.78 for SSA (CHINA is only barely above at 1.84) to 2.46 for WEURO—for reference purposes Table 5 provides the entire range of potentials up to 2050. Such a wide range of figures warrants that the updated WITCH model should be able to explore much contrasted future scenarios. Beyond 2050 the lack of detail in the demographic projections led us to assume a ratio maintained at its 2050 level, for want of a better hypothesis.

Year	USA	WEURO	EEURO	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LACA
2005	2.07	2.49	2.15	1.91	2.16	2.10	2.11	1.81	2.11	1.66	1.90	2.09
2010	2.09	2.44	2.19	1.88	2.16	2.09	2.12	1.80	2.11	1.69	1.90	2.07
2015	2.10	2.44	2.23	1.88	2.17	2.12	2.15	1.80	2.13	1.72	1.92	2.06
2020	2.11	2.45	2.24	1.89	2.13	2.15	2.18	1.79	2.14	1.76	1.93	2.07
2025	2.12	2.48	2.24	1.90	2.13	2.17	2.19	1.79	2.15	1.78	1.94	2.08
2030	2.11	2.51	2.26	1.90	2.15	2.17	2.22	1.79	2.15	1.82	1.95	2.08
2035	2.09	2.50	2.33	1.90	2.17	2.19	2.25	1.78	2.17	1.84	1.95	2.09
2040	2.09	2.48	2.41	1.89	2.18	2.22	2.27	1.78	2.18	1.83	1.95	2.09
2045	2.09	2.46	2.46	1.89	2.17	2.25	2.30	1.78	2.20	1.82	1.96	2.10
2050	2.10	2.46	2.45	1.89	2.16	2.27	2.32	1.78	2.22	1.84	1.96	2.10

Table 5 **Ratio of maximum to observed labour supply resulting from crossing LFPR (Table 3) and AWH (Table 4) potentials, 12 WITCH regions**

III.3. Calibrated free time preference coefficients

Equation (23) is applied to a pre-existing 'business-as-usual' projection of the WITCH model, similar to the B2 scenario of the IPCC's SRES (IPCC, 2000), and to the labour supply potentials presented above (Table 5), assuming systematically normalised $\phi = 1$ trajectories. Following our intuition, despite the simplification of assuming an exogenous *ES*, the trajectories of the updated model including the α coefficients thus computed match the pre-existing projection—in other words, the calibration equation (23) successfully delivers free time preferences matching the observed labour supply gaps in the pre-existing baseline.

Before 2050 these coefficients echo the particulars of both the unexploited labour supply potentials and the pre-existing business-as-usual trajectories. A closer scrutiny of equation (23) suggests they indeed predominantly translate the LFPR fluctuations derived from ILO data. These turn out to embody (*i*) marked increases in free time preference for Eastern Europe (EEURO), China, and to a lesser extent the Transition Economies (TE), Western Europe (WEURO) and the CAJAZ region; (*ii*) a marked decrease in the free time preference of Sub-Saharan Africa (SSA), and (*iii*) relatively stable preferences for the other zones—an arguably plausible set of trends from a broad sociological viewpoint, as partly testified by the historical profiles computed for the larger world economies (*cf.* Annex II). As for their relative levels, quite expectedly the preferences of the different zones are ordered according to the distances to maximum labour supply (*cf.* Table 5 *vs.* Figure 1).

After 2050, when the labour supply potentials are stabilised at their 2050 values, the calibrated α stabilise to close-to-constant values—on trends that evolve by less than 1% every 5 years in any case.

We welcome this as an indication that our specification is fairly appropriate: it brings into consistency stabilised preferences for leisure α and stabilised labour supplies ϕ.

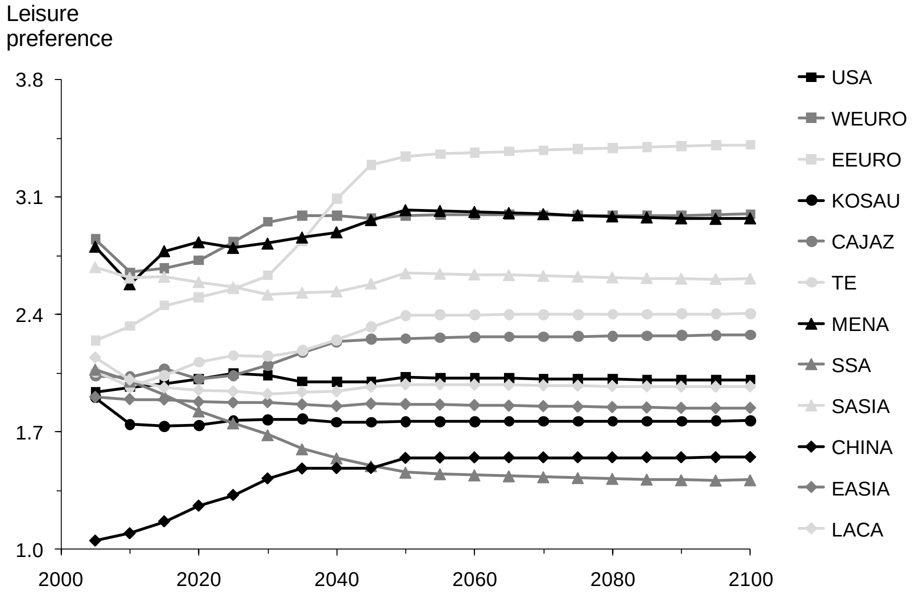

Figure 1 **Leisure preference coefficients calibrated on pre-existing WITCH baseline, 12 WITCH regions**

From 2050 to 2100 the stabilised free time preference values range from 1.41 (SSA, 2100) to 3.41 (EEURO, 2100). Regions are not organised in obvious clusters, but the relative situation of some of them calls for comment:

- The 2 European regions unsurprisingly have the highest coefficients, which seems to confirm some cultural traits commonly lent to them. The strength of the EEURO coefficient might come as a surprise; it can however be explained by a sociological stance towards market labour similar to that of WEURO, echoing a shared cultural heritage, but in a poorer economic context where the marginal utility of consumption is quite higher.
- The MENA coefficient is as high as the WEURO one, but for quite distinct reasons: the average annual working hours of MENA are indeed the highest of all 12 regions, close to 40% above the WEURO AWH (Table 4); LFPR, however, is the lowest of all 12 regions in MENA, for the reason that women are traditionally absent from the labour market in this region. In this particular case any leisure interpretation of the observed and projected time off the labour market is stretched to its limits.
- The SSA and CHINA regions, which combine high AWH and LFPR, have the lowest coefficients despite low GDP *per capita* levels, which imply a relatively high marginal utility of labour.

A general striking result is the resilience of regional singularities to the passing of time. This is somewhat at odds with many prospective analyses of the world's future, which commonly consider some form of global convergence of the lifestyles of even distant regions—the 'global village' hypothesis. It is precisely two instances of such a convergence that the modelling runs presented in our last subsection unfold.

IV. 2 contrasted pathways of free time preferences

This last section implements exogenous modifications of the regional α trajectories in WITCH to produce 2 contrasted pathways in complement to its original BAU:

- One 'American Way of Life' (USWL) pathway in which the free time preferences of all regions converge at a constant rate from their calibration value in 2005 (that reported Figure 1 above) to the USA trend in 2025, then stick to it—*i.e.* to a free time preference stabilised at a level of 2.00 to 2.02.
- One 'Western European Way of Life' (WEWL) pathway in which the free time preferences of all regions converge at a constant rate from their calibration value in 2005 (that reported Figure 1 above) to the Western European trend in 2025, then stick to it—*i.e.* to a free time preference stabilised at a level of 2.99 to 3.00.

The primary reason for this choice is obviously the cultural and economic weight of these 2 regions, and the contrasted working practices backing their development models.

Let us first report on the GDP and labour supply variations induced by the contrasted generalisation of the US *vs.* Western European free time preferences, compared to BAU. Labour supply is measured in man hours, which are computed by directly applying to BAU man hours (products of the BAU labour forces and average working hours) the optimal variations of labour supply ϕ_i induced by the changes in free time preference. A 3% discount rate—the one governing WITCH's own optimisation—is then used to aggregate the variations of both measures over one century.[16]

In a nutshell, the USWL scenario induces substantial GDP impacts, which range from -6% (KOSAU) to +20% (MENA, EEURO), and labour supply impacts, from -5% (KOSAU) to +15% (MENA); in the WEWL scenario these impact respectively range from +2% (EEURO) to -27% (SSA), and from 0% (WEURO, EEURO) to -24% (SSA) (Table 6). Note that discounting the impacts mechanically lends more weight to the earlier years, when regions only gradually drift from their BAU trajectories by converging to one or the other foreign preference. Detailed modeling results reveal indeed that GDP variations symetrically reach +32% (EEURO, USWL, 2095 and 2100) and -32% (SSA, WEWL, 2075 to 2100), while labour supply ones range from -34% (CHINA, WEWL, 2025) to +32% (EEURO, USWL, 2080 to 2100).

[16] To be exhaustive on our computing assumptions: the 5-year time step of WITCH is accounted for by multiplying each discounted year by 5 before adding up.

	USWL scenario		WEWL scenario	
	Disc. GDP	Disc. man hours	Disc. GDP	Disc. man hours
USA	-0%	-0%	-15%	-14%
WEURO	+16%	+14%	+0%	+0%
EEURO	+20%	+13%	+2%	-0%
KOSAU	-6%	-5%	-19%	-17%
CAJAZ	+3%	+2%	-11%	-11%
TE	+5%	+3%	-11%	-10%
MENA	+20%	+15%	+1%	-1%
SSA	-12%	-10%	-27%	-24%
SASIA	+13%	+10%	-6%	-5%
CHINA	-13%	-11%	-28%	-21%
EASIA	-4%	-3%	-19%	-16%
LACA	-2%	-2%	-18%	-16%
WORLD	*+4.2%*	*-0.3%*	*-11.7%*	*-13.8%*

Table 6 **Impact of the 2 scenarios on the discounted 2005 to 2100 GDP and worked man hours, 12 WITCH regions**
Source: authors' computation on WITCH results

Quite expectedly, regions are impacted in a measure connected to how their original (BAU) free time coefficient compares to that of USA or WEURO: converging to a lower coefficient implies a positive variation of labour supply and GDP; converging to a higher free time preference implies a lower labour supply and GDP;[17] moreover, generally speaking, the bigger the gap between the free time preference of a region and that of USA or WEURO, the larger the labour supply and GDP impacts of converging to it.

A closer scrutiny however reveals that GDP impacts tend to be more extended than labour supply ones, both when negative and positive. This is a consequence of the cumulative nature of GDP growth: part of the output of a higher labour supply impacts the GDP of further periods through investment; the fact that the returns on labour are decreasing then explains that GDP losses are closer from labour supply cuts than GDP gains from labour supply increases.

At last, it is worth mentioning that because of the varying shares of each region in the total global GDP and man hours, the global aggregation of the 2 scenarios delivers results that are not easily derived from the disaggregated ones. In the USWL scenario global discounted GDP is increased by 4.2%, while global discounted man hours decrease by 0.3%—the zones that increase their labour supply are on average more productive than those who decrease it. In the WEWL scenario discounted man hours fall by 13.8% and GDP by 11.7%.

Beyond GDP and labour market time, the use of WITCH allows tracking and translating differences in GDP into differences in total primary energy demand and the resulting greenhouse gas emissions (Table 7). The impacts of the 2 scenarios are broadly in line with the GDP gains or losses they induce, but at closer scrutiny reveal some more counter-intuitive mechanisms: compared to BAU, the USWL,

[17] The only exception to this rule is MENA in the WEWL scenario, which indeed records opposite variations in both indicators: an increase in discounted GDP, but a decrease in discounted man hours. This stems from the combined effects of a much smaller, equivocal variation of the free time coefficient, and of sensitivity to the world oil market balance: the laxer market induced by a substantially lower GDP growth turns out to increase the MENA profits.

despite a significantly higher GDP growth, induces both a lower energy and carbon intensity, while the WEWL increases them both. The reason for this is the contrasted impact of both scenarios on global energy markets. The substantial 4.2% increase in discounted GDP caused by the USWL implies increasing tensions on fossil fuel markets, which translate in substantially higher prices that drive the reported improvements in energy demand management and decarbonisation. Conversely, the dramatic 11.7% slack in GDP caused by WEWL considerably eases those tensions and cuts down the incentives to invest in energy efficiency or decarbonisation. The mechanisms at play are most visible in the case of the two central regions of the US and Western Europe for those scenarios that generalise their free time preferences: despite unchanged GDP both their energy consumptions and emissions evolve in quite illustrative ways.

	USWL scenario		WEWL scenario	
	Cum. 1^{ary} E cons.	Cum. emissions	Cum. 1^{ary} E cons.	Cum. emissions
USA	-0.7%	-0.4%	-14.2%	-13.4%
WEURO	+19.1%	+17.3%	+3.4%	+3.5%
EEURO	+21.3%	+17.5%	+6.8%	+5.5%
KOSAU	-5.6%	-4.4%	-16.5%	-13.3%
CAJAZ	+3.4%	+3.3%	-9.8%	-9.0%
TE	+5.5%	+4.1%	-7.4%	-5.2%
MENA	+18.9%	+16.8%	+5.9%	+4.9%
SSA	-11.1%	-4.2%	-20.4%	-7.9%
SASIA	+13.2%	+9.8%	-3.1%	-2.4%
CHINA	-11.3%	-10.4%	-22.9%	-21.5%
EASIA	-4.0%	-3.2%	-15.8%	-14.1%
LACA	-2.4%	-1.3%	-15.8%	-9.1%
WORLD	*+2.5%*	*+1.7%*	*-10.7%*	*-9.1%*

Table 7 **Impact of the two scenarios on cumulated 2005 to 2100 CO_2-equivalent emissions and primary energy consumption, 12 WITCH regions and the world**
Source: authors' computation on WITCH results

Let us finally focus on the comparison of the 12 regions under each of the preference regimes, as far as time allocation is concerned. Our purpose is to test to what extent identical free time preferences induce converging labour supply choices. To do so we have to introduce an indicator of time allocation that, contrary to total discounted man hours, is independent from the labour force count—and report absolute figures rather than mere variations from region-specific BAU situations.

The composite nature of our ϕ_i labour supply coefficient, which merges LFPR and AWH decisions, calls for a composite indicator. One is conveniently given by the share of the maximum available labour supply that is mobilised in each region; this is straightforwardly computed as the ratio of effective over maximum labour supply, ϕ_i over Φ_i in our notations. In the BAU projection, this indicator merely measures the distance between the UNPD and ILO statistics that were used to calibrate WITCH's active populations, and our exogenously set maximum labour supply of 3000 AWH for an LFPR of 95% of the 20- to 69-year old population.

Unsurprisingly, the labour supply ratios of regions rank according to their free time preference coefficients (*cf.* Figure 1 *vs.* Figure 2). The trends up to 2050 directly mirror the UNPD and ILO statistics that were used to calibrate the active populations of each region, and their stabilisation after 2050 only reflects our most simple assumption of a stabilised ratio of active to total population. This assumption appears plausible for most regions, but for the record is probably too brutal for the specific demographic transitions that the SASIA, MENA and TE regions appear to experience—though it is obviously beyond the scope of this paper, and indeed matter for a proper demographic research, to propose more relevant projections.

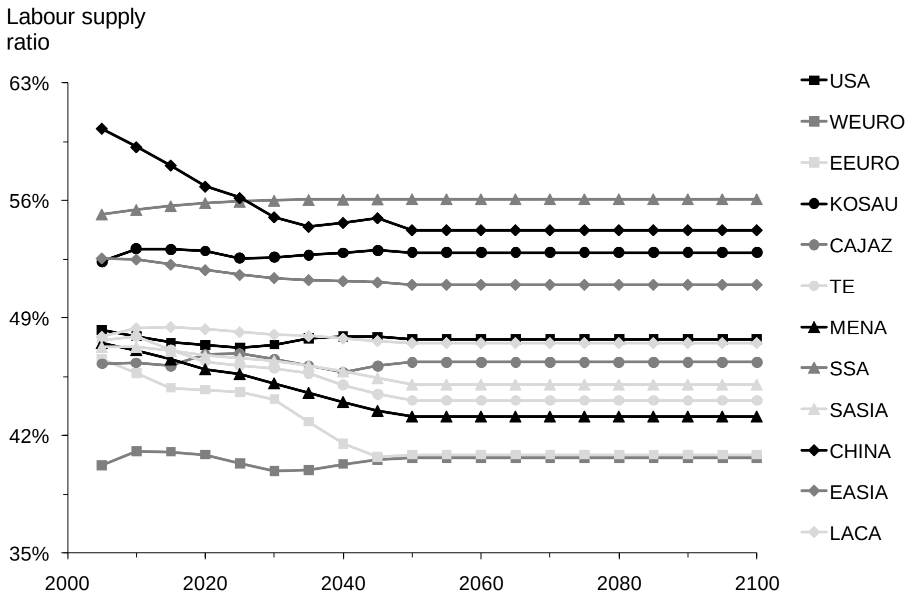

Figure 2 **BAU labour supply ratio from 2005 to 2100, 12 WITCH regions**
Source: WITCH results mirroring UNPD and ILO statistics (*cf.* section I above)

Incidentally, contrary to what was observed for the free time coefficient (Figure 1), two groups loosely detach themselves above and below a 50% ratio frontier. This is a feature quite hard to interpret, considering the composite nature of each group—there does not seem to be any clear cut economic, geographical, historical or sociological trait specific to either group—and it will have to be further investigated.[18]

Notwithstanding these groups, the labour supply ratios remain regionally contrasted up to the 2100 horizon, again contrary to the 'global village' hypothesis of fading out regional idiosyncrasies. By comparison, the labour supply ratios induced by the USWL (Figure 3) and WEWL (Figure 4) scenarios do visibly converge, but only to some extent: the 15-point gap between the lowest and the highest ratio from 2050 to 2100 is reduced to a 7-point one, but remains and does not appear to be shrunk by the passing of time: regions remain quite logically ranked by their comparative labour productivities.

A most notable figure is then the strong similarities between the USA- and the WEURO-induced spreads in the regional labour supply ratios: the shift from one coefficient to the other induces quite systematic absolute variations in the labour supply ratio of about 10 percentage points, without impacting on relative regional positions.

[18] There is no ruling out that this is a mere computational artefact resulting from both the incompleteness of the calibrating statistics, and the ill-suited nature of the regional aggregations of WITCH to labour supply behaviour exploration (energy issues are the original focus of the model).

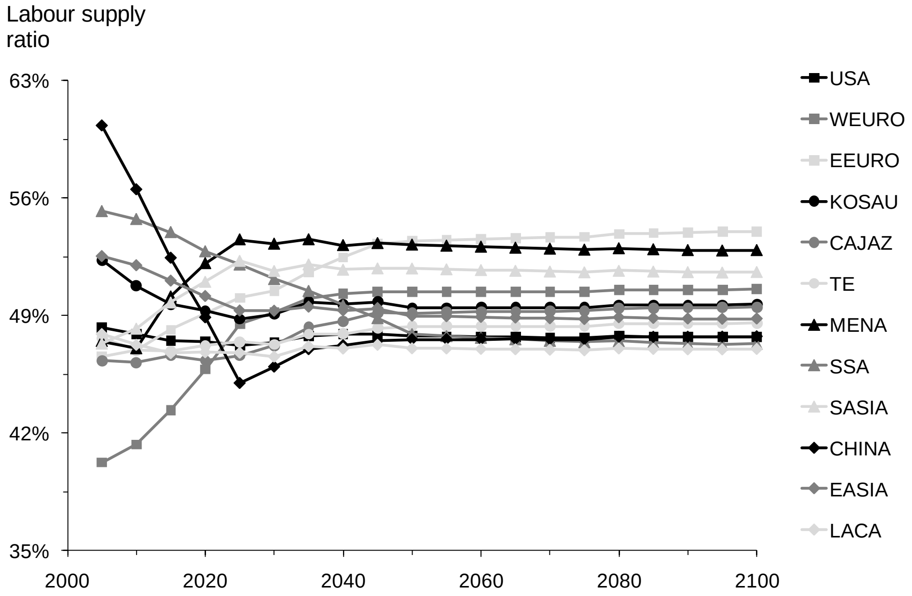

Figure 3 **Labour supply ratio from 2005 to 2100 in the USWL scenario, 12 WITCH regions**
Source: WITCH results

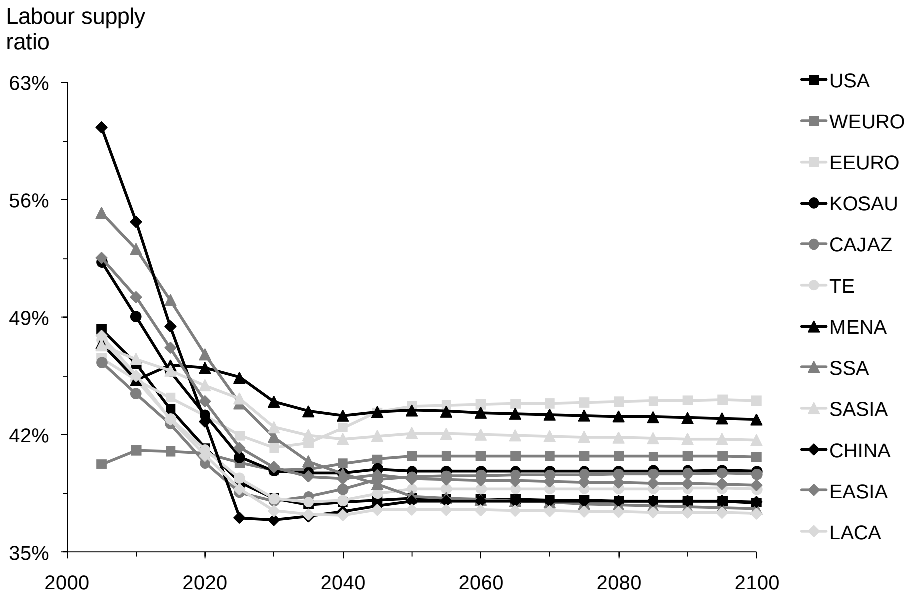

Figure 4 **Labour supply ratio from 2005 to 2100 in the WEWL scenario, 12 WITCH regions**
Source: WITCH results

Conclusion

The USWL and WEWL scenarios are of course illustrative in their radical treatment of free time valuation convergence across the globe. However, they effectively demonstrate that our development of the standard Ramsey intertemporal utility function is operational, thus paving the way for more subtle explorations. Ultimately, the process of calibrating free time coefficients on ILO projections of active population could be reversed. Indeed a closer look at the EAPEP methodology, duly detailed on its website, reveals that it is mostly based on econometric methods constructed on the demographic trends only. To this our model has the potential to substitute a micro-funded, comprehensive approach.

The USWL and WEWL, through their compared impacts on GDP, time allocation, energy consumption and carbon emissions, also give a notion of the vastly contrasted development perspectives that the introduction of a labour supply *vs.* free time trade-off opens. Beyond our deliberate abstraction of free time valuation, a link with distributional issues is easily established, and can indeed reconcile Prescott's conclusion that the lower Western European working hours are justified by higher fiscal pressures: the trade-off may be one between a 'bigger' economy in GDP terms, with reduced non-market time and higher incentives for economic initiative, and an economy combining a higher valuation of free time with stronger social security where a reduced income is more evenly distributed among economic agents. Beyond this trade-off, the 2 scenarios indeed translate to polar growth paradigms, with the AWH and LFPR statistics only tips of the iceberg of social organisations that, way beyond GDP, impact on welfare.

References

Alesina, A.F., Glaeser, E.L., Sacerdote, B. (2006), *Work and Leisure in the US and Europe: Why so Different?*, in *NBER Macroeconomics Annual 2005*, Volume 20, MIT Press, Cambridge, MA: 1-100. http://www.nber.org/chapters/c0073.pdf (accessed January 31st, 2012)

Blanchard, O. (2004), "The Economic Future of Europe", *Journal of Economic Perspectives* 18(4): 3-26.

Blundell, R., Macurdy, T. (1999), "Labor Supply: A review of Alternative Approaches", in Ashenfelter, O., Card, D. (eds.), *Handbook of Labor Economics*, Elsevier, Amsterdam.

Bosetti, V., Carraro, C., Galeotti, M., Massetti E., Tavoni, M. (2006), "WITCH: A World Induced Technical Change Hybrid Model", *The Energy Journal*, Special Issue *Hybrid Modeling of Energy-Environment Policies: Reconciling Bottom-up and Top-down*: 13-38.

Clifton, T.J., Kruse, D., Shepard, E.M. (1996). "Flexible work hours and productivity: Some evidence from the pharmaceutical industry", *Industrial Relations: A Journal of Economy and Society*, 35(1): 123–139.

IPCC, Intergovernmental Panel on Climate Change (2000), *Special Report on Emission Scenarios*, Cambridge University Press, Cambridge, 612 pp.

Kydland, F., Prescott, E.C. (1980), “A Competitive Theory of Fluctuations and the Feasibility and Desirability of Stabilization Policy”, in Fischer, S. (ed.), *Rational Expectations and Economic Policy*, University of Chicago Press, Chicago: 169-198.

Lucas, R.E., Rapping, L.A. (1969), “Real Wages, Employment, and Inflation”, *The Journal of Political Economy* 77 (5): 721-754.

Nordhaus, W.D., Yang. Z. (1996), “A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies”, *American Economic Review* 86 (4): 741-765.

Nordhaus, W.D., Tobin, J. (1973), “Is Growth Obsolete?” in *The Measurement of Economic and Social Performance, Studies in Income and Wealth*, National Bureau of Economic Research, vol.38.

Prescott, E.C. (2004), “Why Do Americans Work So Much More Than Europeans?”, *Federal Reserve Bank of Minneapolis Quarterly Review* 28 (1): 2-13.

Sen, A. (1976), “Real National Income”, *The Review of Economic Studies* 43 (1): 19-39.

Stiglitz, J., Sen, A., Fitoussi, J.-P. (2009), *Report by the Commission on the Measurement of Economic Performance and Social Progress*.
http://www.stiglitz-sen-fitoussi.fr/documents/rapport_anglais.pdf (accessed January 31st, 2012)

Weiss, Y. (2009), “Work and Leisure: A History of Ideas”, *Journal of Labor Economics* 27 (1): 1-20.

Zilibotti, F. (2007), *Economic Possibilities for Our Grandchildren - 75 Years After: A Global Perspective*, Available at SSRN: http://ssrn.com/abstract=1071710

Annex I: updated WITCH demographics

The two tables below present the WITCH demographics of total and active population, as updated following section II above.

Period	USA	WEURO	EEURO	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LACA
1	303	401	103	116	164	373	352	715	1522	1316	589	555
2	318	410	102	121	165	376	386	811	1644	1358	626	588
3	332	416	101	123	166	380	419	917	1764	1400	661	617
4	346	421	100	126	165	384	452	1026	1877	1435	693	644
5	359	424	99	128	164	386	483	1138	1979	1457	723	668
6	370	425	97	130	162	385	511	1251	2068	1467	749	689
7	380	426	95	130	160	384	537	1365	2145	1466	771	705
8	389	426	92	131	157	382	561	1478	2214	1459	789	717
9	397	425	90	130	154	380	583	1588	2272	1444	802	724
10	404	424	88	130	151	376	600	1694	2318	1421	811	728
11	411	421	85	129	149	370	613	1795	2360	1399	817	733
12	417	418	82	128	146	364	624	1886	2393	1376	821	735
13	422	414	80	127	143	358	631	1967	2416	1354	822	736
14	426	410	78	126	141	353	635	2033	2427	1332	821	735
15	429	405	76	124	139	348	636	2085	2428	1310	817	731
16	431	399	74	123	137	343	634	2121	2418	1289	811	725
17	431	393	73	122	135	338	629	2140	2396	1267	803	717
18	431	387	72	120	133	333	620	2141	2364	1246	792	707
19	429	380	72	118	131	328	609	2124	2322	1225	779	695
20	426	373	71	117	130	323	595	2091	2269	1204	765	682
21	424	366	71	115	128	319	582	2062	2224	1186	752	670
22	422	361	71	114	127	316	571	2037	2184	1170	740	659
23	420	356	70	112	126	313	562	2016	2150	1156	731	650
24	418	352	70	111	125	310	554	1999	2121	1144	722	643
25	417	349	70	111	125	308	548	1985	2097	1134	715	636
26	416	347	70	110	124	306	543	1973	2079	1126	710	632
27	415	345	70	109	124	305	539	1965	2065	1120	706	628
28	414	343	70	109	123	304	537	1960	2055	1117	703	625
29	414	343	70	109	123	304	535	1957	2051	1115	702	624
30	414	343	70	109	123	304	535	1957	2051	1115	702	624

Table 8 Total population of the 12 WITCH regions, 2005 to 2150 (30 periods) [19]

[19] The model extends to 2150 to avoid settling on a transversal condition (it only imposes positive investment). Results are customarily not reported beyond 2100.

Period	USA	WEURO	EEURO	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LACA
1	157	194	48	52	86	173	122	287	591	768	289	252
2	164	202	47	55	87	179	139	332	660	800	317	278
3	171	204	46	58	86	181	153	385	728	819	341	302
4	177	203	45	59	85	180	165	446	793	819	363	323
5	181	199	43	59	83	178	179	513	854	812	382	340
6	186	195	41	59	81	177	191	587	909	799	399	354
7	191	191	39	59	78	175	202	664	956	785	412	364
8	196	188	37	59	75	172	211	744	993	768	422	370
9	200	186	34	59	72	168	218	823	1017	749	429	373
10	203	184	32	58	70	163	222	901	1029	725	433	372
11	206	183	31	58	69	160	227	955	1048	713	436	375
12	210	181	30	58	67	157	230	1004	1062	702	438	376
13	212	179	29	57	66	155	233	1047	1072	691	439	377
14	214	178	29	57	65	152	235	1082	1077	679	438	376
15	216	175	28	56	64	150	235	1110	1078	668	436	374
16	216	173	27	55	63	148	234	1129	1073	657	433	371
17	217	170	27	55	62	146	232	1139	1064	646	429	367
18	216	168	27	54	62	144	229	1139	1049	636	423	362
19	216	165	26	53	61	142	225	1131	1031	625	416	356
20	214	162	26	53	60	140	220	1113	1007	614	408	349
21	213	159	26	52	59	138	215	1097	987	605	401	343
22	212	156	26	51	59	136	211	1084	969	596	395	337
23	211	154	26	51	58	135	208	1073	954	589	390	333
24	210	153	26	50	58	134	205	1064	941	583	386	329
25	209	151	26	50	58	133	202	1056	931	578	382	326
26	209	150	26	50	57	132	201	1050	923	574	379	323
27	208	149	26	49	57	132	199	1046	916	571	377	321
28	208	149	26	49	57	131	198	1043	912	569	375	320
29	208	149	26	49	57	131	198	1041	910	568	375	319
30	208	149	26	49	57	131	198	1041	910	568	375	319

Table 9 Active population of the 12 WITCH regions, 2005 to 2150 (30 periods)

Annex II: estimated historical free time preference coefficients

This second annex presents and briefly comments upon estimated historical free time preference coefficients for the 10 current largest economies. The estimates are derived from equation (16) above based on a set of data and assumptions quite similar to that implemented in sections II and III:

- Total and active population counts in five-year age groups are again systematically derived from ILO's EAPEP exercise; they allow computing LFPR margins in the sense retained throughout our analysis (labour supply increase from a 95% LFPR for the 20 to 69 year-old population).

- Annual working hours are derived from OECD or ILO, and matched to our 3,000-hour maximum to define AWH margins; contrary to section II year-specific data are used whenever available.

- Each economy's aggregate production function is assumed to be a standard Cobb-Douglas of labour and capital, with a cost-share of capital β systematically rounded up to 0.3. This induces a simplified expression for the α coefficients:

$$\forall t \quad \alpha_t = \frac{\Phi_t - \phi_t}{\phi_t}(1-\beta)\frac{Y_t}{C_t}\frac{N_t}{L_t} \tag{24}$$

LFPR and AWH margins are combined to compute potential labour supplies Φ, considering normalised effective labour supplies $\phi = 1$. Savings rates are drawn from the World Development Indicators database of the Worldbank[20] to complete the data necessary for estimation.

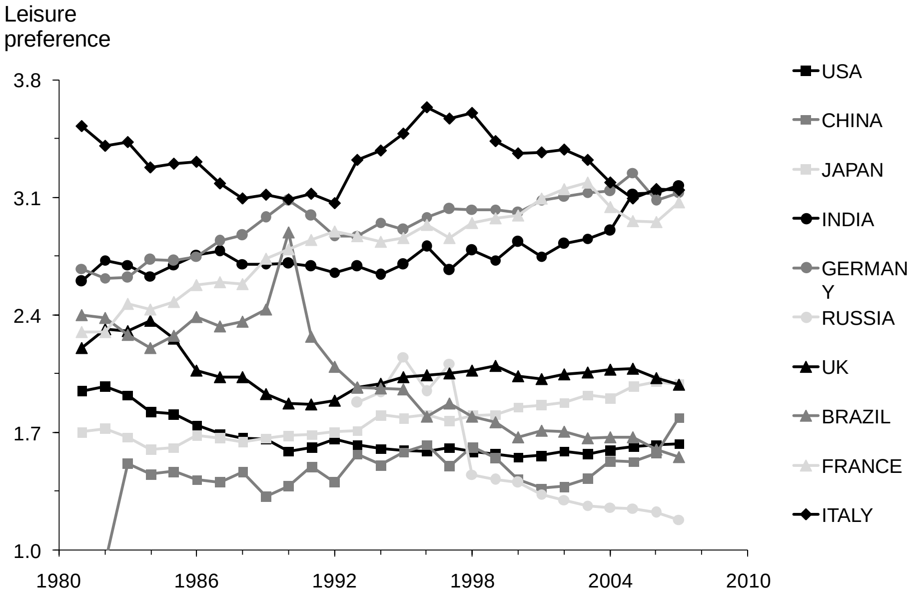

Figure 5 **Estimated free time preference coefficients for the 10 current largest economies, 1981-20007**

The estimates thus obtained (Figure 5) confirm (*i*) a relative stability of the US free time preference, at least from the 1990's on; (*ii*) some slight upward trend for the time preference of the available Western European and CAJAZ economies, that is Germany, France and Italy on one hand, Japan on the other hand—but the UK appears, as in other sociological dimensions, more aligned on the US trend than on the Western European one; (*iii*) some upward trend for China, although much weaker than that deriving from prospective 2005 to 2050 calibration (*cf.* Figure 1 above).

The data on Russia, considering the political turmoil over the period, is delicate to comment upon, although a downward trend appears to concretise from the end of the 1990's on. The marked downward trend for Brazil and the slight upward trend for India contradict to some extent the 2005-2050 prospective calibration of the corresponding LACA and SASIA zones; this translates some inspiring incompatibility between our micro-funded approach to labour supply and the econometric methods of the EAPEP—a matter of further research.

[20] *Cf.* http://data.worldbank.org/data-catalog/world-development-indicators (accessed May 2012).

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

http://www.feem.it/getpage.aspx?id=73&sez=Publications&padre=20&tab=1
http://papers.ssrn.com/sol3/JELJOUR_Results.cfm?form_name=journalbrowse&journal_id=266659
http://ideas.repec.org/s/fem/femwpa.html
http://www.econis.eu/LNG=EN/FAM?PPN=505954494
http://ageconsearch.umn.edu/handle/35978
http://www.bepress.com/feem/

NOTE DI LAVORO PUBLISHED IN 2012

CCSD	1.2012	Valentina Bosetti, Michela Catenacci, Giulia Fiorese and Elena Verdolini: The Future Prospect of PV and CSP Solar Technologies: An Expert Elicitation Survey
CCSD	2.2012	Francesco Bosello, Fabio Eboli and Roberta Pierfederici: Assessing the Economic Impacts of Climate Change. An Updated CGE Point of View
CCSD	3.2012	Simone Borghesi, Giulio Cainelli and Massimiliano Mozzanti: Brown Sunsets and Green Dawns in the Industrial Sector: Environmental Innovations, Firm Behavior and the European Emission Trading
CCSD	4.2012	Stergios Athanassoglou and Valentina Bosetti and Gauthier de Maere d'Aertrycke: Ambiguous Aggregation of Expert Opinions: The Case of Optimal R&D Investment
CCSD	5.2012	William Brock, Gustav Engstrom and Anastasios Xepapadeas: Energy Balance Climate Models and the Spatial Structure of Optimal Mitigation Policies
CCSD	6.2012	Gabriel Chan, Robert Stavins, Robert Stowe and Richard Sweeney: The SO2 Allowance Trading System and the Clean Air Act Amendments of 1990: Reflections on Twenty Years of Policy Innovation
ERM	7.2012	Claudio Morana: Oil Price Dynamics, Macro-Finance Interactions and the Role of Financial Speculation
ES	8.2012	Gérard Mondello: The Equivalence of Strict Liability and Negligence Rule: A « Trompe l'œil » Perspective
CCSD	9.2012	Eva Schmid, Brigitte Knopf and Nico Bauer: REMIND-D: A Hybrid Energy-Economy Model of Germany
CCSD	10.2012	Nadia Ameli and Daniel M. Kammen: The Linkage Between Income Distribution and Clean Energy Investments: Addressing Financing Cost
CCSD	11.2012	Valentina Bosetti and Thomas Longden: Light Duty Vehicle Transportation and Global Climate Policy: The Importance of Electric Drive Vehicles
ERM	12.2012	Giorgio Gualberti, Morgan Bazilian, Erik Haites and Maria da Graça Carvalho: Development Finance for Universal Energy Access
CCSD	13.2012	Ines Österle: Fossil Fuel Extraction and Climate Policy: A Review of the Green Paradox with Endogenous Resource Exploration
ES	14.2012	Marco Alderighi, Marcella Nicolini and Claudio A. Piga: Combined Effects of Load Factors and Booking Time on Fares: Insights from the Yield Management of a Low-Cost Airline
ERM	15.2012	Lion Hirth: The Market Value of Variable Renewables
CCSD	16.2012	F. Souty, T. Brunelle, P. Dumas, B. Dorin, P. Ciais and R. Crassous: The Nexus Land-Use Model, an Approach Articulating Biophysical Potentials and Economic Dynamics to Model Competition for Land-Uses
CCSD	17.2012	Erik Ansink, Michael Gengenbach and Hans-Peter Weikard: River Sharing and Water Trade
CCSD	18.2012	Carlo Carraro, Enrica De Cian and Massimo Tavoni: Human Capital, Innovation, and Climate Policy: An Integrated Assessment
CCSD	19.2012	Melania Michetti and Ramiro Parrado: Improving Land-use modelling within CGE to assess Forest-based Mitigation Potential and Costs
CCSD	20.2012	William Brock, Gustav Engstrom and Anastasios Xepapadeas: Energy Balance Climate Models, Damage Reservoirs and the Time Profile of Climate Change Policy
ES	21.2012	Alireza Naghavi and Yingyi Tsai: Cross-Border Intellectual Property Rights: Contract Enforcement and Absorptive Capacity
CCSD	22.2012	Raphael Calel and Antoine Dechezleprêtre: Environmental Policy and Directed Technological Change: Evidence from the European carbon market
ERM	23.2012	Matteo Manera, Marcella Nicolini and Ilaria Vignati: Returns in Commodities Futures Markets and Financial Speculation: A Multivariate GARCH Approach
ERM	24.2012	Alessandro Cologni and Matteo Manera: Oil Revenues, Ethnic Fragmentation and Political Transition of Authoritarian Regimes
ERM	25.2012	Sanya Carley, Sameeksha Desai and Morgan Bazilian: Energy-Based Economic Development: Mapping the Developing Country Context
ES	26.2012	Andreas Groth, Michael Ghil, Stéphane Hallegatte and Patrice Dumas: The Role of Oscillatory Modes in U.S. Business Cycles
CCSD	27.2012	Enrica De Cian and Ramiro Parrado: Technology Spillovers Embodied in International Trade: Intertemporal, regional and sectoral effects in a global CGE
ERM	28.2012	Claudio Morana: The Oil price-Macroeconomy Relationship since the Mid- 1980s: A global perspective
CCSD	29.2012	Katie Johnson and Margaretha Breil: Conceptualizing Urban Adaptation to Climate Change Findings from an Applied Adaptation Assessment Framework

ES	30.2012	Angelo Bencivenga, Margaretha Breil, Mariaester Cassinelli, Livio Chiarullo and Annalisa Percoco: The Possibilities for the Development of Tourism in the Appennino Lucano Val d'Agri Lagonegrese National Park: A Participative Qualitative-Quantitative Approach
CCSD	31.2012	Tim Swanson and Ben Groom: Regulating Global Biodiversity: What is the Problem?
CCSD	32.2012	J. Andrew Kelly and Herman R.J. Vollebergh: Adaptive Policy Mechanisms for Transboundary Air Pollution Regulation: Reasons and Recommendations
CCSD	33.2012	Antoine Dechezleprêtre, Richard Perkins and Eric Neumayer: Regulatory Distance and the Transfer of New Environmentally Sound Technologies: Evidence from the Automobile Sector
CCSD	34.2012	Baptiste Perrissin Fabert, Patrice Dumas and Jean-Charles Hourcade: What Social Cost of Carbon? A mapping of the Climate Debate
ERM	35.2012	Ludovico Alcorta, Morgan Bazilian, Giuseppe De Simone and Ascha Pedersen: Return on Investment from Industrial Energy Efficiency: Evidence from Developing Countries
CCSD	36.2012	Stefan P. Schleicher and Angela Köppl: Scanning for Global Greenhouse Gas Emissions Reduction Targets and their Distributions
CCSD	37.2012	Sergio Currarini and Friederike Menge: Identity, Homophily and In-Group Bias
CCSD	38.2012	Dominik Karos: Coalition Formation in Generalized Apex Games
CCSD	39.2012	Xiaodong Liu, Eleonora Patacchini, Yves Zenou and Lung-Fei Lee: Criminal Networks: Who is the Key Player?
CCSD	40.2012	Nizar Allouch: On the Private Provision of Public Goods on Networks
CCSD	41.2012	Efthymios Athanasiou and Giacomo Valletta: On Sharing the Benefits of Communication
CCSD	42.2012	Jan-Peter Siedlarek: Intermediation in Networks
CCSD	43.2012	Matthew Ranson and Robert N. Stavins: Post-Durban Climate Policy Architecture Based on Linkage of Cap-and-Trade Systems
CCSD	44.2012	Valentina Bosetti and Frédéric Ghersi: Beyond GDP: Modelling Labour Supply as a 'Free Time' Trade-off in a Multiregional Optimal Growth Model