Optimal Dynamic Carbon Taxes in a Climate-Economy Model with Distortionary Fiscal Policy
Online Appendix

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1 Proof of Proposition 1

This section proves the validity of the primal approach setup as laid out in Proposition 1 of the paper. This proof follows closely the method outlined in Chari and Kehoe (1999), with appropriate extensions and revisions to accommodate the multi-sector climate-economy setting of this paper. Consider first the representative household's problem and associated first order conditions (FOCs). Note that I assume throughout that the solution to the household's problem is interior. The consumer maximizes household utility U_0 while taking climate change T_t as given:

$$U_0 \equiv \sum_{t=0}^{\infty} \beta^t U(C_t, L_t, T_t) \tag{1}$$

Every period, he faces the following flow budget constraint:

$$C_t + \rho_t B_{t+1} + K_{t+1} \leq w_t(1-\tau_{lt})L_t + \{1 + (r_t - \delta)(1 - \tau_{kt})\} K_t + B_t + \Pi_t \tag{2}$$

Letting γ_t be Lagrange multiplier on (2) in period t, his FOCs are given by:

$[C_t]$:

$$\gamma_t = \beta^t U_{ct} \tag{3}$$

$[L_t]$:

$$\frac{-U_{lt}}{U_{ct}} = w_t(1-\tau_{lt}) \tag{4}$$

$[K_{t+1}]$:

$$\gamma_t = \beta\gamma_{t+1} \{1 + (r_{t+1} - \delta)(1 - \tau_{kt+1})\} \tag{5}$$

$[B_{t+1}]$:

$$U_{ct}\rho_t = \beta U_{ct+1} \tag{6}$$

Next, consider the final goods producer's problem, which is to choose L_{1t}, K_{1t}, and E_t to solve:

$$\max F(T_t, K_{1t}, L_{1t}, E_t) - w_t L_t - p_{Et} E_t - r_t K_t$$

Letting F_{jt} denote the first derivative of the production function with respect to factor j, the associated first order conditions are:

$$\begin{aligned} F_{lt} &= w_t \\ F_{Et} &= p_{Et} \\ F_{kt} &= r_t \end{aligned} \tag{7}$$

The energy producer solves:

$$\max(p_{Et} - \tau_{Et})E_t - w_t L_{2t} - r_t K_{2t}$$

subject to:

$$E_t = F_{2t}(L_{2t}, K_{2t})$$

The associated FOCs are:

$$\begin{aligned} (p_{Et} - \tau_{Et})F_{2lt} &= w_t \\ (p_{Et} - \tau_{Et})F_{2kt} &= r_t \end{aligned} \tag{8}$$

Since the quantitative model incorporates both government consumption G_t^C as well as non-negative social transfers G_t^T which are provided to households (e.g., unemployment insurance, disability insurance, etc.), this proof incorporates both types of government spending. The only difference from the core model as set up in the paper is that G_t^T has to be added to the consumer budget constraint (2) and subtracted from the government budget constraint in each period.

Direction: If the allocations and initial conditions constitute a competitive equilibrium, then constraints (RC)-(IMP) are satisfied. If we are in a competitive equilibrium, the consumer's FOCs (3)-(6) will be satisfied. Note that we can multiply both sides on the FOC for capital savings (5) by K_t to find that:

$$\left[\gamma_t - \gamma_{t+1}\left\{1 + (r_{t+1} - \delta)(1 - \tau_{kt+1})\right\}\right] K_{t+1} = 0 \tag{9}$$

Similarly, for bonds we have that:

$$\left[\gamma_t \rho_t - \gamma_{t+1}\right] B_{t+1} = 0 \tag{10}$$

Also note that the consumer's transversality conditions necessarily hold in a competitive equilibrium:

$$\begin{aligned} \lim_{t\to\infty} \gamma_t B_{t+1} &= 0 \\ \lim_{t\to\infty} \gamma_t K_{t+1} &= 0 \end{aligned} \tag{11}$$

In a competitive equilibrium, the consumer's flow budget constraint (2) also needs to be satisfied. Multiplying both sides of the flow budget constraint in each period by γ_t yields:

$$\gamma_t \left[C_t + \rho_t B_{t+1} + K_{t+1}\right] = \gamma_t \left[w_t(1-\tau_{lt})L_t + \{1 + (r_t - \delta)(1-\tau_{kt})\} K_t + B_t + G_t^T + \Pi_t\right] \quad (12)$$

Note that energy sector profits in competitive equilibrium will be equal to zero, given the assumptions of constant returns to scale and perfect competition in energy production. Taking note of this fact and summing equation (12) over all t leads to:

$$\sum_{t=0}^{\infty}\gamma_t \left[C_t + \rho_t B_{t+1} + K_{t+1} - w_t(1-\tau_{lt})L_t - \{1 + (r_t - \delta)(1-\tau_{kt})\} K_t - B_t - G_t^T\right] = 0 \quad (13)$$

Except for the time zero bonds and capital return, all of the other terms relating to capital and bond cancel out of equation (13) out as per equations (9), (10) and the transversality conditions (11). We thus end up with:

$$\sum_{t=0}^{\infty}\gamma_t \left[C_t - w_t(1-\tau_{lt})L_t - G_t^T\right] = \gamma_0 \left[K_0 \{1 + (r_0 - \delta)(1-\tau_{k_0})\} + B_0\right] \quad (14)$$

Next, based on the consumer's and firm's FOCs, one can substitute out for γ_t, $w_t(1-\tau_{lt})$, and r_0 in (14) to obtain the implementability constraint (**??**):

$$\sum_{t=0}^{\infty}\beta^t \left[U_{ct}C_t + U_{lt}L_t - U_{ct}G_t^T\right] = U_{c0} \left[K_0 \{1 + (F_{k0} - \delta)(1-\tau_{k_0})\} + B_0\right] \quad (15)$$

We have thus shown that competitive equilibrium implies that the implementability constraint is satisfied. Next, to show that the final goods resource constraint holds in competitive equilibrium, (i) add up the consumer and government flow budget constraints, (ii) substitute in the bond market clearing condition, (iii) invoke the definition of energy sector profits, (iv) substitute in capital and labor market clearing conditions, (v) substitute in for factor prices based on the final good producer's FOCs, and (vi) invoke Euler's theorem based on the assumption of constant returns to scale in final goods production. Finally, the carbon cycle constraint and the energy producer's resource constraint hold by definition in competitive equilibrium.

Direction: If constraints(RC)-(IMP) are satisfied, one can construct competitive equilibrium. This direction of the proof proceeds by construction. First, let factor prices be given by:

$$
\begin{aligned}
F_{lt} &= w_t \\
F_{Et} &= p_{Et} \\
F_{kt} &= r_t
\end{aligned} \tag{16}
$$

These factor prices are obviously consistent with profit maximization in the final goods sector, as required in a competitive equilibrium. Next, let the return on bonds be given by:

$$\rho_t = \beta U_{ct+1}/U_{ct}$$

Again, this price is clearly consistent with utility maximization as per the agent's FOC (6).

Let the labor tax rate be determined by:

$$
\begin{aligned}
-U_{lt}/U_{ct} &= (1-\tau_{lt})F_{lt} \\
1+\frac{U_{lt}/U_{ct}}{F_{lt}} &= \tau_{lt}
\end{aligned}
$$

Similarly, let the tax rate on capital income for each time $t > 0$ be defined via:

$$
\begin{aligned}
U_{ct} &= \beta U_{ct+1}\left\{1+(F_{kt+1}-\delta)(1-\tau_{kt+1})\right\} \\
\tau_{kt+1} &= 1-\frac{U_{ct}/\beta U_{ct+1}-1}{(F_{kt+1}-\delta)}
\end{aligned}
$$

As per the consumer's and final goods producer's FOCs , these tax rates will clearly be consistent with utility and profit maximization.

Let the tax on emissions be given as:

$$\tau_{Et} = p_{Et} - \frac{F_{1lt}}{F_{2lt}}$$

Again, this tax is clearly consistent with profit maximization in the energy and final goods production sectors as per FOCs (8) and (7).

To construct bond holdings in period t, first multiply the consumer budget constraint (2) by its Lagrange multiplier γ_t and sum over all periods *from period t onwards*:

$$\sum_{s=t}^{\infty}\gamma_s\left[C_s+\rho_s B_{s+1}+K_{t+1}-w_s(1-\tau_{ls})L_s-\{1+(r_s-\delta)(1-\tau_{ks})\}-B_s-\Pi_s-G_t^T\right]=0$$

In a competitive equilibrium, the consumer's FOCs and transversality conditions (11) must hold, implying that all future terms relating to capital and bond holdings cancel out. We are thus left with:

$$\sum_{s=t}^{\infty}\gamma_s\left[C_s - w_s(1-\tau_{ls})L_s - \Pi_s - G_t^T\right] + \gamma_t\left\{1+(r_t-\delta)(1-\tau_{kt})\right\}K_t = \gamma_t B_t \tag{17}$$

Once again, we can use the agent's and the firms' FOCs to substitute out prices in equation (17) and obtain:

$$\sum_{s=t}^{\infty}\frac{\beta^{s-t}U_{cs}}{U_{ct}}\left[C_s + \frac{U_{ls}}{U_{cs}}L_s - G_s^T\right] + \frac{U_{ct-1}}{\beta U_{ct}}K_t = B_t$$

This equation defines the unique bond holdings that are consistent with a competitive equilibrium, given allocations.

Being based on agents' and firms' first order conditions and constraints, the prices and policies defined above are clearly consistent with utility and profit maximization. It remains to be shown that all the necessary constraints for competitive equilibrium are satisfied.

The final goods resource constraint, the carbon cycle constraint, the energy production resource constraints, and the factor market clearing conditions all hold by assumption. By Walras' law, demonstrating that the consumer budget constraint is satisfied is sufficient to imply that the government budget constraint must be satisfied also.

Note that only the consumer's competitive equilibrium-budget constraint is relevant to our proof, as we seek to demonstrate that our constructed prices, bond holdings, and policies are constitute a competitive equilibrium. In a competitive equilibrium, the household's intertemporal budget constraint must hold, along with the consumer's FOCs, implying (9) and (10), and the consumer's transversality conditions. The key point, then, is that, at the prices selected above, the consumer's competitive equilibrium-budget constraint then becomes identical to the implementability constraint, which holds by assumption. Thus, the competitive equilibrium budget constraint at the chosen prices is satisfied $\square$.

2 Non-Separable Preferences over Climate Change

The benchmark COMET model assumes that households' preferences are (additively) separable between climate change and consumption/leisure. A key implication of this assumption is that climate change does not affect the set of allocations decentralizable as a competitive equilibrium other than through its effects on output. If, however, climate change were a relative complement or substitute for leisure, this would no longer be the case, and the optimal carbon tax formulation would have to be modified. In particular, relaxing this assumption does not change the planner's problem relative to the benchmark except that U_{ct} and U_{lt} are now functions of temperature change T_t. As a result, it is easy to show that the marginal damage of temperature change in period $t > 0$ (in utils) is then given by:

$$\underbrace{U_{Tt}}_{\text{Utility damage}} + \underbrace{\lambda_{1t}\frac{\partial Y_t}{\partial T_t}}_{\text{Output damage}} + \underbrace{\phi[U_{cTt}C_t + U_{lTt}L_t]}_{\text{Offer curve impact}} = \underbrace{-\xi_t}_{\text{Marginal damage from } T_t} \tag{18}$$

where ϕ is the Lagrange multiplier on the competitive equilibrium implementability constraint. In addition to utility losses and output damages, climate change can thus impact welfare in a third way in this setting. If temperature affects households' offer curves, it changes the set of allocations that can be decentralized as a competitive equilibrium. In other words, the government may not be able to induce households to supply the same amount of labor or choose the same consumption paths if temperature change affects households' marginal utilities of consumption and leisure. For example, if climate change is complementary with leisure, households will be less willing to supply labor at a given wage as the climate warms.

Combining the planner's first order conditions for energy inputs E_t, total labor supply L_t, and energy sector labor L_{2t} with (18), and comparing with the energy producer's optimality conditions leads to the following expression implicitly defining the optimal tax in this setting:

$$\begin{aligned}\tau^*_{Et} &= \sum_{j=0}^{\infty}\beta^j\left\{\frac{U_{Tt+j}}{\lambda_{1t}} + \frac{\lambda_{1t+j}}{\lambda_{1t}}\frac{\partial Y_{t+j}}{\partial T_{t+j}} + \frac{\phi}{\lambda_{1t}}[U_{cTt+j}C_{t+j} + U_{lTt+j}L_{t+j}]\right\}\frac{dT_{t+j}}{dE_t} \\ &= \underbrace{\frac{\tau^{Pigou,U}_{Et}}{MCF_t}}_{\text{Utility damages}} + \sum_{j=0}^{\infty}\beta^j\left\{\underbrace{\frac{\lambda_{1t+j}}{\lambda_{1t}}\frac{\partial Y_{t+j}}{\partial T_{t+j}}}_{\text{Output damages}} + \underbrace{\frac{(MCF_t - 1)}{MCF_t}\left[\frac{U_{cTt+j}C_{t+j} + U_{lTt+j}L_{t+j}}{U_{cct}C_t + U_{ct} + U_{lct}L_t}\right]}_{\text{Offer curve impacts}}\right\}\frac{dT_{t+j}}{dE_t}\end{aligned} \tag{19}$$

where the second equation follows from substituting in for ϕ from the planner's first order condition for C_t, multiplication by U_{ct}/U_{ct}, and invoking the definition of the marginal cost of public funds ($MCF \equiv \frac{\lambda_{1t}}{U_{ct}}$).

Expression (19) leads to two main insights. On the one hand, non-separability in preferences does not change the key theoretical findings of this paper. That is, it is still the case that (i) utility damages are internalized differently from production damages, and (ii) the optimal tax component for output damages is Pigouvian if the planner optimally sets capital income taxes to zero from time t onwards (implying that $\frac{\lambda_{1t+j}}{\lambda_{1t}} = \frac{U_{ct+j}}{U_{ct}}$ for all $j \geq 0$).

On the other hand, the optimal total carbon tax can now be larger or smaller than the Pigouvian tax, depending on the sign and size of the size and sign of the impacts of temperature change on the agents' offer curves. In particular, the offer curve impact will increase the level of the optimal carbon tax if climate change utility impacts are *complementary with leisure* and *a substitute for consumption*. Intuitively, this result goes back to the Corlett and Hague (1953) rule that goods which are relative complements to leisure should be taxed relatively more. Relatedly, Schwarz and Repetto (2000) demonstrate that the welfare costs of the interaction between labor income taxes and pollution taxes are reduced to the extent that improved environmental quality can increase labor supply. Carbone and Smith (2008) provide a quantitative analysis of the implications of non-separability in a model of particulate matter pollution in the U.S. economy.

Unfortunately, the literature provides very little empirical evidence on the likely magnitudes and signs of the complementarity between climate change and leisure and consumption, respectively. The climate amenity value estimates underlying the DICE damage function include modest increases in the value of time use for cold regions and negative impacts for warm regions, based on moderate but positive time use value estimates for the United States by Nordhaus (1998). Neidell and Zivin (2010) find that overall labor supply in the United States does not appear responsive to changes in weather-induced temperature variation. However, labor supply in climate-sensitive industries (agriculture, construction, utilities, etc.) does decrease significantly and sizably during hot weather. A well-known concern in extrapolating from weather variation impacts to climate change is that they do not account for long-term adaptation (e.g., Mendelsohn, Nordhaus, and Shaw 1994). Indeed, Neidell and Zivin do find that the impacts of warm temperatures are weaker in warmer regions. Future research in this area would thus be highly valuable for more accurate calibration of environmental tax interaction studies.

3 Demonstrate Compatibility with Balanced Growth

This section demonstrates that the chosen preference specification is consistent with a balanced growth path. Let $\pounds_t = 1 - l_t$ denote *leisure*. To demonstrate that utility specification

$$\begin{aligned} U(c_t, l_t, T_t) &= \left\{ \frac{\left[c_t \cdot (1-\phi l_t)^{\gamma}\right]^{1-\sigma}}{1-\sigma} \right\} + + \frac{\left(1+\alpha_0 T_t^2\right)^{-(1-\sigma)}}{1-\sigma} \\ &= \left\{ \frac{\left[c_t \cdot v(\pounds)\right]^{1-\sigma}}{1-\sigma} \right\} + + \frac{\left(1+\alpha_0 T_t^2\right)^{-(1-\sigma)}}{1-\sigma} \end{aligned}$$

is compatible with a balanced growth path for $[\sigma = 1.5 > 1]$, one has to show that (King et al., 2001):

1. $\{v(\pounds)\}^{1-\sigma}$ is decreasing
2. $\{v(\pounds)\}^{1-\sigma}$ is convex

3. $-\sigma v(\pounds)v''(\pounds) > (1-2\sigma)[v'(\pounds)]^2$

The first step is thus to express $(1-\phi l_t)$ as a function of leisure $v(\pounds_t)$:

$$\begin{aligned}(1-\phi l_t) &= \phi+(1-\phi)-\phi l_t \\ &= \phi(1-l_t)+(1-\phi) \\ &= \phi\pounds_t+(1-\phi)\end{aligned}$$

The first and second derivatives of $v(\pounds_t)$ are correspondingly given by:

$$\begin{aligned}v(\pounds) &= [\phi\pounds+(1-\phi)]^{\gamma} \\ v'(\pounds) &= \gamma\phi[\phi\pounds+(1-\phi)]^{\gamma-1} \\ v''(\pounds) &= \gamma\phi^2[\gamma-1][\phi\pounds+(1-\phi)]^{\gamma-2}\end{aligned} \tag{20}$$

(1) Ensure that $\{v(\pounds)\}^{1-\sigma}$ is decreasing:

$$\begin{aligned}v(\pounds)^{1-\sigma} &= [\phi\pounds+(1-\phi)]^{\gamma(1-\sigma)} \\ v'(\pounds)^{1-\sigma} &= \gamma\phi(1-\sigma)[\phi\pounds+(1-\phi)]^{\gamma(1-\sigma)-1}\end{aligned} \tag{21}$$

Given that $(1-\sigma)<0$, expression (21) is negative if $\phi>0$, $\gamma>0$, and $\phi\pounds+(1-\phi)>0$. A sufficient condition for the latter to be true is that $\phi\in[0,1]$. For low values of the Frisch elasticity of labor supply and for $n^*=0.2272$, in the baseline calibration, there are cases when $\phi>1$. In those cases, however, $\phi\pounds+(1-\phi)>0$, implying that the conditions for $\{v(\pounds)\}^{1-\sigma}$ being decreasing are still satisfied.

(2) Ensure that $\{v(\pounds)\}^{1-\sigma}$ is convex:

$$v^{''}(\pounds)^{1-\sigma} = \gamma(1-\sigma)\phi^2\left[\gamma(1-\sigma)-1\right]\cdot\left[\phi\pounds+(1-\phi)\right]^{\gamma(1-\sigma)-2} \tag{22}$$

Since $(1-\sigma)<0$ and $[\gamma(1-\sigma)-1]<0$ (for $\gamma>0$), expression (22) will be positive as long as the conditions derived in (1) are satisfied.

(3) Ensure that $-\sigma v(\pounds)v''(\pounds)) > (1-2\sigma)[v'(\pounds))]^2$:

Substituting in from (20) and collecting terms yields:

$$(-\sigma)\gamma\phi^2[\gamma-1][\phi\pounds+(1-\phi)]^{2\gamma-2} > (1-2\sigma)\gamma^2\phi^2[\phi\pounds+(1-\phi)]^{2\gamma-2}$$

which can be reduced to condition:

$$\frac{\sigma}{(1-\sigma)} < \gamma \tag{23}$$

Once again, since $\sigma = 1.5$, condition (23) is satisfied as long as $\gamma > 0$.

4 Robustness: Multi-Country Setting

4.1 Case 1: Transfers Across Countries Are Possible

Assume there are n countries with the economic structure as in the benchmark model. The representative consumer in country i has preferences over his consumption C_{it}, labor supply, L_{it}, and global temperature change T_t (separably). Letting γ_t^i denote the weight that the global planner attaches to country $i's$ utility at time t, he seeks to maximize:

$$\max \sum_{i=1}^{n} \sum_{t=0}^{\infty} \beta^t \gamma_t^i U(C_{it}, L_{it}, T_t)$$

Letting Υ_{it} denote country $i's$ *net* foreign transfers in period t (which can be positive or negative), its economy-wide budget constraint is then given by:

$$F_{1it}(T_t, L_{1it}, K_{1it}, E_{it}) + (1-\delta)K_{it} \geq C_{it} + G_{it} + \Upsilon_{it} + K_{it+1} \tag{24}$$

If the global planner can assign international transfers Υ_{it}, he effectively faces a single international resource constraint for the final consumption-investment good:[1]

$$\sum_{i=1}^{n} \{F_{1it}(T_t, L_{1it}, K_{1it}, E_{it}) + (1-\delta)K_{it} - C_{it} - G_{it} - K_{it+1}\} \geq 0 \tag{25}$$

Note that (25) holds regardless of whether we allow countries to trade the energy and consumption good. Assume that country i can export energy E_{it}^X and import energy E_{it}^M. Maintaining the notation of E_{it} as the total energy input used by country i in final goods production in period t, its energy budget constraint becomes:

$$E_{it} \leq F_{2it}(A_{Eit}, K_{2it}, L_{2it}) - E_{it}^X + E_{it}^M \tag{26}$$

[1] To see this, note that the sum of international transfers cannot be negative $\left(\sum_{i=1}^{n} \Upsilon_{it} \geq 0\right)$, and substitute in from each country's resource constraint (24).

Letting p_{Et} denote the (now internationally harmonized) price of the energy good, country $i's$ economy-wide budget constraint becomes:

$$F_{1it}(T_t, L_{1it}, K_{1it}, E_{it}) + (1-\delta)K_{it} + p_{Et}(E_{it}^X - E_{it}^M) \geq C_{it} + G_{it} + \Upsilon_{it} + K_{it+1} \tag{27}$$

However, summing (27) across countries again leads to (25) as the sum of net energy exports must equal zero. While tradeability of the energy good does change energy resource constraints from n country-specific ones to a single-global one, this does not alter the optimal (excise) carbon tax formula.

The global planner's problem in this multi-country setting with transfers and energy resource trade is given by:

$$\begin{aligned}
&\max \sum_{i}^{n}\sum_{t=0}^{\infty}\beta^t \left\{\gamma_t^i U(C_{it}, L_{it}, T_t) + \phi_i \left(U_{cit}C_{it} + U_{lit}L_{it}\right)\right\} \\
&+\sum_{t=0}^{\infty}\beta^t\lambda_{1t}\sum_{i}\left[F_{1it}(T_t, L_{1it}, K_{1it}, E_{it}) + (1-\delta)K_{it} - C_{it} - G_{it} - K_{it+1}\right] \\
&+\sum_{t=0}^{\infty}\beta^t\xi_t[T_t - F_t(S_0, \sum_i E_{i0}, \sum_i E_{i1}, ...\sum_i E_{it})] \\
&+\sum_{i}^{n}\sum_{t=0}^{\infty}\beta^t\lambda_{lit}\left[L_{it} - L_{i1t} - L_{i2t}\right] \\
&+\sum_{i}^{n}\sum_{t=0}^{\infty}\beta^t\lambda_{kit}\left[K_{it} - K_{i1t} - K_{i1t}\right] \\
&+\sum_{t=0}^{\infty}\beta^t\omega_t\left[\sum_{i=1}^{n}F_{2it}(A_{Eit}, K_{2it}, L_{2it}) - \sum_{i=1}^{n}E_{it}\right] \\
&-\sum_{i}^{n}\phi_i\left\{U_{ci0}\left[K_{i0}\left\{1 + (F_{ki0} - \delta)(1 - \overline{\tau_{ki0}})\right\}\right]\right\}
\end{aligned}$$

Combining the planner's FOCs leads to the following optimality condition for carbon energy:

$$F_{Eit} - \frac{F_{1iLt}}{F_{2Lit}} = \frac{1}{\lambda_{1t}}\sum_{j=0}^{\infty}\beta^j\xi_{t+j}\frac{\partial T_{t+j}}{\partial E_{it}} \tag{28}$$

In words, (28) says that the wedge between country $i's$ marginal product of energy F_{Eit} and the private production costs of energy $\frac{F_{1iLt}}{F_{2Lit}}$ should be equal to the present discounted value of the shadow cost of the additional carbon ξ_{t+j} in the atmosphere, valued by the uniform global public marginal utility of resources λ_{1t}. As is clear from (28), this optimal wedge is uniform across countries as the right-hand side of (28) does not depend on i. More precisely, substituting in the decentralized equilibrium conditions (e.g., $F_{Eit} = p_{Eit}$) and comparing () with the energy producer's profit-maximization conditions demonstrates that the optimal allocation can be decentralized by a uniform global carbon tax implicitly defined by:

$$\begin{aligned} \tau^*_{Eit} &= \sum_{j=0}^{\infty}\sum_{m=1}^{n}\beta^j \left(\gamma_t^m \frac{(-U_{Tmt+j})}{\lambda_{1t}} + \frac{\lambda_{1t+j}}{\lambda_{1t}}\left(\frac{-\partial Y^m_{t+j}}{\partial T_{t+j}}\right)\right)\frac{\partial T_{t+j}}{\partial E_{it}} && (29) \\ &= \tau^*_{Et} && (30) \end{aligned}$$

Finally, multiplying the utility damage term in (29) by $\frac{U_{Cmt}}{U_{Cmt}}$ and invoking the definition of the MCF yields the desired result of Corollary 2.

4.2 Case 2: Resource Transfers Across Countries Are Not Possible

Assume now that the planner cannot re-allocate resources across countries directly.[2] The critical difference in this setup is that the planner now faces n national resource constraints rather than a single global resource constraint. In particular, the planner's problem becomes:

$$\begin{aligned} &\max \sum_{i}^{n}\sum_{t=0}^{\infty}\beta^t \left\{ \gamma_t^i U(C_{it}, L_{it}, T_t) + \phi_i \underbrace{(U_{cit}C_{it} + U_{lit}L_{it})}_{\equiv H_t} \right\} \\ &+\sum_{i}\sum_{t=0}^{\infty}\beta^t\lambda_{1it}\left[F_{1it}(T_t, L_{1it}, K_{1it}, E_{it}) + (1-\delta)K_{it} - C_{it} - G_{it} - K_{it+1}\right] \\ &+\sum_{t=0}^{\infty}\beta^t\xi_t[T_t - F_t(S_0, \sum_i E_{i0}, \sum_i E_{i1}, ...\sum_i E_{it})] \\ &+\sum_{i}^{n}\sum_{t=0}^{\infty}\beta^t\lambda_{lit}\left[L_{it} - L_{i1t} - L_{i2t}\right] \\ &+\sum_{i}^{n}\sum_{t=0}^{\infty}\beta^t\lambda_{kit}\left[K_{it} - K_{i1t} - K_{i1t}\right] \\ &+\sum_{i}^{n}\sum_{t=0}^{\infty}\beta^t\omega_{it}\left[F_{2it}(A_{Eit}, K_{2it}, L_{2it}) - E_{it}\right] \\ &-\sum_{i}^{n}\phi_i\left\{U_{ci0}\left[K_{i0}\left\{1 + (F_{ki0}-\delta)(1-\overline{\tau_{ki0}})\right\}\right]\right\} \end{aligned}$$

[2] As discussed in the main paper, this setting rules out transfers as well as trade conditions that could substitute for fiscal transfers.

Combining the planner's FOCs for carbon energy now leads to the following condition:

$$F_{Eit} - \frac{F_{1iLt}}{F_{2Lit}} = \frac{1}{\lambda_{1it}} \sum_{j=0}^{\infty} \beta^j \xi_{t+j} \frac{\partial T_{t+j}}{\partial E_{it}} \tag{31}$$

As in Case 1, (31) shows that the wedge between each country's marginal product of energy F_{Eit} and its private production cost $\frac{F_{1iLt}}{F_{2Lit}}$ is equal to the present discounted value of the shadow cost of additional atmospheric carbon. However, in contrast to (28), these damages are translated into national carbon taxes at different rates based on each country's marginal value of public resources λ_{1it}. Whether the optimal carbon tax remains uniform in this setting thus depends on whether the planner's welfare weights on each country offset the differences in marginal utilities of public income. In particular, by substituting in the planner's FOCs for temperature change, comparing to decentralized behavior of firms, and through some algebraic manipulations, one can show that the optimal carbon tax in country i for $t > 0$ is implicitly defined by:

$$\tau_{Eit} = \frac{1}{\lambda_{1it}} \sum_{j=0}^{\infty} \sum_{m=0}^{n} \beta^j \left(\lambda_{1mt}\right) \left\{ \gamma^m \frac{(-U_{Tmt+j}/U_{cmt})}{MCF_{mt}} + \frac{\lambda_{1mt+j}}{\lambda_{1mt}} \left(\frac{-\partial Y^m_{t+j}}{\partial T_{t+j}}\right) \right\} \frac{\partial T_{t+j}}{\partial E_{it}} \tag{32}$$

The planner's FOC with respect to C_{it} for $t > 0$ yields the following optimality condition:

$$\lambda_{1it} = \gamma^i_t U^i_{ct} + \phi_i H^i_{ct} \tag{33}$$

In words, (33) indicates that the scarcity value of public resources in country i at time t is given by the welfare-weighted marginal utility of consumption $\gamma^i_t U_{ct}$ plus a term that captures the effect of a change in consumption on the planner's ability to decentralize the optimal allocation with distortionary taxes in country i ($\phi_i H^i_{ct}$). Plugging into (32) yields:

$$\tau_{Eit} = \sum_{j=0}^{\infty} \sum_{m=0}^{n} \beta^j \left(\frac{\gamma^m_t U^m_{ct} + \phi_m H^m_{ct}}{\gamma^i_t U^i_{ct} + \phi_i H^i_{ct}} \right) \left\{ \gamma^m \frac{(-U_{Tmt+j}/U_{cmt})}{MCF_{mt}} + \frac{\lambda_{1mt+j}}{\lambda_{1mt}} \left(\frac{-\partial Y^m_{t+j}}{\partial T_{t+j}}\right) \right\} \frac{\partial T_{t+j}}{\partial E_{it}} \tag{34}$$

Next, assume that the planner puts the following (Negishi) weights on utility in country i at time t :

$$\gamma^i_t = \frac{\overline{U_{ct}} + \overline{\phi H}_{ct} - \phi_i H^i_{ct}}{U^i_{ct}} \tag{35}$$

Plugging (35) into (34) and rearranging shows that the optimal carbon tax in this setting is once again uniform across countries, completing the proof of Corollary 3:

$$\begin{aligned}\tau_{Eit} &= \sum_{j=0}^{\infty}\sum_{m=0}^{n}\beta^{j}\left\{\gamma^{m}\frac{(-U_{Tmt+j}/U_{cmt})}{MCF_{mt}}+\frac{\lambda_{1mt+j}}{\lambda_{1mt}}(\frac{-\partial Y_{t+j}^{m}}{\partial T_{t+j}})\right\}\frac{\partial T_{t+j}}{\partial E_{it}} \\ &= \tau_{Et}^{*}\end{aligned}$$

Finally, in order to derive the general expression for the optimal country-specific carbon tax, simply multiply the weight term in (32) by $\frac{(U_{cmt}/U_{cmt})}{(U_{cit}/U_{cit})}$ and substitute in from the definition of the MCF.

5 Calibration: Marginal Cost of Public Funds Survey

Table 3 below summarize estimates from the literature on the marginal cost of public funds and the closely related concepts of the marginal excess burden (MEB), and the marginal welfare cost (MWC) of taxes. In order to infer the plausible magnitude of a global MCF estimate, I proceed as follows.

First, for studies reporting a range of estimates, I use the authors' preferred or central estimate when available. Otherwise, the mean estimate is used (See table for details).

Second, for studies reporting MCF estimates for multiple tax instruments and for all taxes, I use the "all taxes" value. For studies reporting several estimates across different tax instruments but no overall estimate, each estimate is used as separate observation and averaged along with the other estimates.

Third, for studies that estimate the marginal excess burden (MEB) or the marginal deadweight loss ($MDWL$) from taxes, I use $1 + MEB$ and $1 + MDWL$ as measures of the MCF. Please note that the results in Table 3 are reported with (+1) added for those studies. As discussed in the paper, this is not technically accurate due to differences in the precise definitions. However, in reality, there are considerable differences in definitions and calculation methods across studies even within each measurement concept (see, e.g., Jorgenson and Yun (1991) on discussion of MEB measurement differences), implying that estimates across studies may in any case not be perfectly comparable.

Fourth, I compute unweighted averages across estimates within each country. The base year (2005) PPP GDP-weighted average of the central estimates across countries is 1.486.[3]

[3] Year 2005 GDP data stem from the World Bank Development Indicators data base.

Authors	Data	Results	Notes
Saez, Slemrod, and Giertz (2012)	U.S.	1.195	MEB (across-the-board proportional tax increase)
Parry (2002)	U.S.	1.27; 1.39	MWC (labor income), "middle" parameters, spending on public goods/transfers
Jorgenson and Yun (2001)	U.S.	1.266	MEB (all taxes)
Feldstein (1999)	U.S.	2.06	MCF (personal income)
Ahmed and Croushore (1994)	U.S.	1.121 to 1.167	MCF (labor income)
Jorgenson and Yun (1991)	U.S.	1.391	MEB (all taxes)
Fullerton and Henderson (1989)	U.S.	1.247	MEB (personal income), "standard elasticities"
Fullerton and Henderson (1989)	U.S.	1.310	MEB (corporate income), "standard elasticities"
Browning (1987)	U.S.	1.318; 1.469	MWC (labor income), author's preferred estimates
Ballard, Shoven, and Whalley (1985)	U.S.	1.332	MEB (all taxes), value for parameters in which authors have "most confidence"
Stuart (1984)	U.S.	1.41	MEB (labor income), average across all estimates reported in Table 2
Kleven and Kreiner (2006)	UK	1.26	MCF (labor income), proportional tax increase, "natural baseline scenario" S6
Kleven and Kreiner (2006)	Italy	1.52	MCF (labor income), proportional tax increase, "natural baseline scenario" S6
Kleven and Kreiner (2006)	France	1.72	MCF (labor income), proportional tax increase, "natural baseline scenario" S6
Kleven and Kreiner (2006)	Germany	1.85	MCF (labor income), proportional tax increase, "natural baseline scenario" S6
Kleven and Kreiner (2006)	Denmark	2.20	MCF (labor income), proportional tax increase, "natural baseline scenario" S6
Hansson and Stuart (1985)	Sweden	1.55	MCF (labor income), average of "best guess" parameter estimates for spending on public goods/ transfers, across historical and const.progr. tax increase
Baylor and Beausejour (2004)	Canada	1.32	MWC (personal income), "central" parameter values
Baylor and Beausejour (2004)	Canada	1.37	MWC (corporate income), "central" parameter values
Ruggeri (1999)	Canada	1.13	MCF (personal income), proportional increase
Thirsk and Moore (1991)	Canada	1.30 to 1.43	MWC (labor income), range for "intermediate parameters"
Ahmad and Stern (1987)	India	1.66-2.15	MCF (excise taxes) (as reported by Auriol and Warlters, 2012)
Ahmad and Stern (1987)	India	1.59-2.12	MCF (sales taxes) (as reported by Auriol and Warlters, 2012)
Ahmad and Stern (1987)	India	1.54-2.17	MCF (import taxes) (as reported by Auriol and Warlters, 2012)
Auriol and Warlters (2012)	S.S Africa	1.21	MCF (all taxes), "base case estimate" of average across 38 countries
Diewert and Lawrence (2002)	Australia	1.48	MEB (capital income), final model year (1994) value
Campbell and Bond (1997)	Australia	1.194;1.239	MCF (labor income)

Table 1: MCF Literature Review

6 Calibration of Leisure Preferences

The Frisch elasticity of labor supply $\left(\eta^F = \frac{\partial l_t}{\partial w_t}\frac{w_t}{l_t}|_{\overline{\lambda_t}}\right)$ in the current setting is easily derived:

$$\eta^F = \frac{U_{lt}}{l_t\left[U_{llt} - \frac{U_{clt}^2}{U_{cct}}\right]} \quad (36)$$

$$= \frac{(1-\phi l_t)}{\phi l_t}\frac{-1}{\left[[\gamma(1-\sigma)-1] - \frac{\gamma(1-\sigma)^2}{(-\sigma)}\right]} \quad (37)$$

Similarly, the representative household's first order condition for labor supply is given by:

$$\frac{-U_{lt}}{U_{ct}} = w_t(1-\tau_{lt})$$

$$\frac{c_t\gamma\phi}{(1-\phi n_t)} = w_t(1-\tau_{lt}) \quad (38)$$

I use the two equations (37) and (38) to solve for the two unknowns γ and ϕ as a function of η^F, l_t, $c_t, (1-\tau_{lt})w_t$, and σ. I calibrate to $t = 2005$ values from the data. The choice to calibrate to the base year is made to increase consistency across model runs with different fiscal scenarios. That is, steady-state labor supply depends on the steady-state labor income tax rate, which is an endogenous outcome of the model and can differ across the fiscal scenarios considered. Differences in steady-state labor supply would then require differences in preference parameters across model runs. These changes would obfuscate the interpretation of the results as being due to changes in tax policy and constraints across model scenarios. Observed base-year values for consumption and labor supply are given from the data and have the attractive trait of being constant across fiscal scenarios. An important exception is the calibration to the first-best (lump sum taxation) setting, which sets ($\tau_{l2005} = 0$).

Baseline labor supply l_{2005} is estimated using OECD data on "Average annual hours actually worked per worker" and on employment rates across all available countries in the model base year 2005. Given Jones, Manuelli, and Rossi's (1993) assumption that adults have 14.5 hours per day available for work, the GDP-weighted average time endowment share spent on labor is $l_{2005} = 0.2272$. Base year consumption per capita c_{2005} is calculated using World Bank data[4] on household final consumption expenditure as share of GDP across all available countries, which is 61% for 2005. The gross wage w_{2005} is calculated as the marginal product of labor in the base year $\left(w_t = \frac{(1-\alpha-v)Y_{2005}}{l_{2005}N_{2005}}\right)$. The base year average marginal labor tax rate τ_{l2005} is the GDP-weighted average labor-consumption effective tax based on estimates from the literature (see below). Finally, the value $\sigma = 1.5$ is chosen to match the DICE model (Nordhaus, 2010). The resulting estimates in all distortionary tax model runs are $\gamma = 0.7303$ and $\phi = 2.2343$. In the first-best model run, $\tau_{l2005} = 0$ but all other parameters remain the same, yielding $\gamma = 1.2985$ and $\phi = 2.0785$.

4 *World Development Indicators* data base, World Bank.

7 Calibration: Energy Production Function Labor Share

This section describes the estimation of the labor share in carbon-based energy production. Industry data from the U.S. Bureau of Economic Analysis ("BEA") on *components of value added by industry* were used for this calculation. Two technical points deserve special attention. First, well-known problems arise with regards to the treatment of mineral resources in industry and national accounts (BEA, 1994). Resource rents are not accounted for explicitly and are thus included as capital returns. Given this concern, and given that the baseline model and calibration focus on carbon energy in sufficiently large supply so as to not earn Hotelling rents (e.g., coal), I thus focus on data from the non-oil and gas energy industries as listed below. Second, in using the BEA data, it is necessary to distribute proprietors' income between capital or labor. In each of the industries considered, base year proprietors' income shares of value added are small, between 4.2% and 5.4%. I follow Valentyni and Herrendorf (2007) in calculating capital and labor shares without proprietors' income. This approach assumes that proprietor's income is split between capital and labor in the same way as other income.[5]

Table 2 summarizes the results from these factor elasticity calculations.

		2000-2010 Average:	
Industry Title	2002 NAICS	Labor Share	GDP Share
Mining, except oil and gas	212	0.606	0.0029
Support activities for mining	213	0.641	0.0024
Utilities	22	0.382	0.0175
Manufacturing of petroleum and coal products	324	0.181	0.0084
All Private Industries		0.719	
Weighted Average Share:		0.368	
Weighted Average Share w/o petroleum/coal manufacturing:		0.438	

Table 2: Labor Share of Value Added in Energy Production

A labor share value of $\alpha_E = 0.403$ is used a compromise between the estimates with and without petroleum and coal products manufacturing, respectively.

8 Calibration: Clean Energy Production

The additional cost of zero emissions energy production E_t^{clean} - conceptually analogous to emissions reductions at a given energy input level - is based on the DICE model (Nordhaus, 2008).

[5] Very specifically, labor shares are calculated via:

$$\widehat{\alpha_E} = \frac{COM}{COM + \{GOS - BTP - PROP\}}$$

where COM is compensation of employees (including employer contributions to pensions, etc.), GOS is gross operating surplus, BTP is net business current transfer payments, and $PROP$ is proprietors' income, measured in the data as "Other gross operating surplus, noncorporate."

However, as both carbon-based and clean energy use are endogenous in the COMET, the DICE abatement cost estimates - which are based on the fraction of emissions abated relative to the BAU scenario - need to be translated into a per-ton cost function. First, I thus compute a grid of total abatement costs in DICE for different amounts of clean energy produced in each decade through the year 2265.[6] Second, I approximate these costs through a logistic function:

$$\Theta_t(E_t^{clean}) = \frac{\overline{a}P_t^{backstop}}{1 + a_t \exp(b_{0t} - b_{1t}(E_t^{clean}))^{b_2}} \cdot E_t^{clean} \tag{39}$$

where $P_t^{backstop}$ denotes the backstop technology price in year t, taken directly from DICE.[7] The time-dependent coefficients α_t, b_{0t}, and b_{1t} are modeled as $\alpha_t = \alpha_1 + \alpha_2 \log(t)$ and $b_{it} = b_{i1} + b_{i2}\log(t)$ for $i = 0, 1$.[8] The remaining parameters in (39) are solved for numerically by minimizing the sum of squared errors between the present discounted total costs implied by (39) and those computed based on the DICE model. The results are: $\overline{a} = 0.9245$; $\alpha_1 = 49.9096$; $\alpha_2 = 1.0995$; $b_{01} = 15.5724$; $b_{02} = 3.4648$; $b_{11} = 13.0210$; $b_{22} = 1.5725$; and $b_2 = 0.0921$.

9 Calibration: Effective Tax Rate Estimates

6 Ranging from 0 to 250 billion metric tons of carbon-equivalent energy in increments of 10 tons. The calculations assume a constant marginal abatement cost for clean energy production in excess of the number of tons that would correspond to 100% emissions reduction in DICE, equal to the backstop technology price.

7 Here, the time-dependent coefficients α_t, b_{0t}, and b_{1t} are modeled as $\alpha_t = \alpha_1 + \alpha_2 \log(t)$ and $b_{it} = b_{i1} + b_{i2}\log(t)$ for $i = 0, 1$. These functional forms were chosen after solving non-parametrically for the optimal sequence of t different values for α_t, b_{0t}, and b_{1t}, which followed a time-logarithmic trend extremely closely.

8 These functional forms were chosen after solving non-parametrically for the optimal sequence of t different values for α_t, b_{0t}, and b_{1t}, which followed a time-logarithmic trend extremely closely.

Country	Avg. of Estimates τ_l	τ_k	τ_c	Sources
Albania	33.4			World Bank (2007)
Argentina	37.3	43.5		IMF (2012), Chen and Mintz (2015)
Armenia	38.5			World Bank (2007)
Australia	24.1	45.5	10.6	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015)
Austria	40.9	28.9	15.8	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Azerbaijan	29.8			World Bank (2007)
Bangladesh		15.4		Chen and Mintz (2015)
Belarus	35.5			World Bank (2007)
Belgium	44.2	30.7	15.1	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Bolivia		21.0		Chen and Mintz (2015)
Bosnia	34.9			World Bank (2007)
Botswana		13.6		Chen and Mintz (2015)
Brazil	28.7	28.6	26.3	Azevedo and Fasolo (2015), Gandullia et al. (2012), IMF (2012), Chen and Mintz (2015)
Bulgaria	39	13.4		World Bank (2007), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Canada	25.7	43.7	11.7	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Chad		39.1		Chen and Mintz (2015)
Chile	18.5	7.7		World Bank (2007), IMF (2012), Chen and Mintz (2015)
China	35.4	31.7		Gandullia et al. (2012), Chen and Mintz (2015)
Colombia	55.7	31.6		IMF (2012), Chen and Mintz (2015)
Costa Rica		27.9		Chen and Mintz (2015)
Croatia	40.3	10.8		World Bank (2007), Chen and Mintz (2015), Devereux et al. (2009)
Cyprus		17		Devereux et al. (2009)
Czech Republic	38.6	24	17.5	Carey & Rabesona (2002), World Bank (2007), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Denmark	38	42.7	21.1	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Dominican Republic		23.4		Chen and Mintz (2015)
Ecuador		19.7		Chen and Mintz (2015)
Egypt	59.5	13.5		IMF (2012), Chen and Mintz (2015)

Table 3: MCF Literature Review

Country	Avg. of Estimates τ_l	τ_k	τ_c	Sources
Estonia	40.7	16.1		World Bank (2007), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Ethiopia		15.8		Chen and Mintz (2015)
Fiji		18.3		Chen and Mintz (2015)
Finland	42.0	31.6	19.0	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
France	42.4	47.4	15.4	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Georgia	26.7	20.9		World Bank (2007), Chen and Mintz (2015)
Germany	38.5	35.7	13.5	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Ghana		14.6		Carey & Rabesona (2002)
Greece	36.8	23.6	15.4	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Guyana		36.9		Chen and Mintz (2015)
Hong Kong		35.5		Chen and Mintz (2015)
Hungary	44	25.8	21.5	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Iceland	23.6	16.1		IMF (2012), Chen and Mintz (2015)
India	0.8	26	15	IMF (2012), Chen and Mintz (2015), Ganduilla et al. (2012), Poirson (2006)
Indonesia	8.2	21.8		IMF (2012), Chen and Mintz (2015), Ganduilla et al. (2012)
Iran		13.3		Chen and Mintz (2015)
Ireland	22.9	24		Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009), World Bank (2007)
Israel	15.8	17.8		IMF (2012), Chen and Mintz (2015)
Italy	40.7	34.1	14.1	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Jamaica		17.0		Chen and Mintz (2015)
Japan	25.3	45.2	6.7	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Jordan	23.9	13.0		IMF (2012), Chen and Mintz (2015)
Kazakhstan	28.2	25.6		World Bank (2007), IMF (2012), Chen and Mintz (2015)
Kenya		15.1		IMF (2012), Chen and Mintz (2015)
Korea	15.6	29.1	14.2	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), World Bank (2007)
Kuwait		26.8		Chen and Mintz (2015)
Kyrgyz Republic	31.6			World Bank (2007)

Table 4: MCF Literature Review

	Avg. of Estimates			
Country	τ_l	τ_k	τ_c	Sources
Latvia	42.5	11.0		IMF (2012), Chen and Mintz (2015), Devereux et al. (2009), World Bank (2007)
Lesotho		29.0		Chen and Mintz (2015)
Lithuania	43.7	12.7		IMF (2012), Devereux et al. (2009), World Bank (2007)
Luxembourg	22.1	25.3		IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Macedonia	41.4	14.0		Devereux et al. (2009)
Madagascar		16.6		Chen and Mintz (2015)
Malaysia		17.8		IMF (2012), Chen and Mintz (2015)
Mali	33.0			IMF (2015)
Malta		27.1		Devereux et al. (2009)
Mauritius		11.3		Chen and Mintz (2015)
Mexico	15.5	17.4		IMF (2012), Chen and Mintz (2015),
Moldova	32.4			World Bank (2007)
Morocco	35.7	14.5		IMF (2012), Chen and Mintz (2015)
Netherlands	33.8	30.6	15.6	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
New Zealand	16.6	28.1	16.0	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015)
Nigeria		12.0		Chen and Mintz (2015)
Norway	34.6	31.8	21.7	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Pakistan		25.8		Chen and Mintz (2015)
Panama		22.8		Chen and Mintz (2015)
Paraguay		16.2		Chen and Mintz (2015)
Peru	35.8	22.8		IMF (2012), Chen and Mintz (2015)
Philippines		26.4		IMF (2012), Chen and Mintz (2015)
Poland	39.3	23.0	17.1	Carey & Rabesona (2002), World Bank (2007), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Portugal	28.2	25.0	15.9	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Qatar		12.0		Chen and Mintz (2015)
Romania	44.1	15.1		World Bank (2007), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Russia	31.0	33.5		IMF (2012), Chen and Mintz (2015)

Table 5: MCF Literature Review

	Avg. of Estimates			
Country	τ_l	τ_k	τ_c	Sources
Rwanda		18.5		Chen and Mintz (2015)
Saudi Arabia		20.0		IMF (2012), Chen and Mintz (2015)
Serbia	42.2	-2.4		World Bank (2007), Chen and Mintz (2015)
Sierra Leone		18.5		Chen and Mintz (2015)
Singapore		10.2		Chen and Mintz (2015)
Slovak Republic	36.5	16.4		IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Slovenia	38.0	20.6		IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
South Africa	13.7	14.9		Gandullia et al. (2012), Chen and Mintz (2015)
Spain	51.2	42.6	14.5	Carey & Rabesona (2002), World Bank (2007), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Switzerland	23.4	30.8	8.5	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Taiwan		13.6		Chen and Mintz (2015)
Tajikistan	29.6			World Bank (2007)
Tanzania		18.0		Chen and Mintz (2015)
Thailand	14.3	12.8		World Bank (2007), IMF (2012), Chen and Mintz (2015)
Trinidad		15.1		Chen and Mintz (2015)
Tunisia		22.1		Chen and Mintz (2015)
Turkey	40.5	23.9		World Bank (2007), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Uganda	13.6	13.4		World Bank (2007), IMF (2012), Chen and Mintz (2015)
Ukraine	39.2	11.1		World Bank (2007), IMF (2012), Chen and Mintz (2015)
United Kingdom	25.0	37.7	14.3	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
United States	24.0	41.1	5.6	Carey & Rabesona (2002), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)
Uruguay		35.1		Chen and Mintz (2015)
Uzbekistan	38.0	37.8		World Bank (2007), Chen and Mintz (2015)
Venezuela		30.2		Chen and Mintz (2015)
Vietnam	16.1	12.7		World Bank (2007), Chen and Mintz (2015)
Zambia		17.4		
				Carey & Rabesona (2002), World Bank (2007), IMF (2012), Chen and Mintz (2015), Devereux et al. (2009)

Table 6: MCF Literature Review

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