The challenge of addressing consumption pollutants with fiscal policy

GREGMAR I. GALINATO, Corresponding Author
School of Economic Sciences, Washington State University, Pullman, WA 99164, USA. Tel.: 509-335-6382. Email: ggalinato@wsu.edu

ASIF ISLAM
Enterprise Analysis Unit, Development Economics Indicators Group, The World Bank, Washington, DC, USA. Email: aislam@worldbank.org

ONLINE APPENDIX

Appendix A

Proof of Lemma 1

To derive the effect of *g* and *t* on *h*, we totally differentiate (6) to find

$$\frac{dh}{dg} = -\frac{u_c\left(\frac{f_{hg}}{p(Q)}\right)+u_{cc}\left(\frac{f_h-1}{p(Q)}\right)\frac{f_g}{p(Q)}}{u_{cc}(f_h-1)^2+u_c f_{hh}} = -\frac{u_c\left(\frac{f_{hg}}{p(Q)}\right)}{u_c f_{hh}}. \tag{A1}$$

Thus, as long as $f_{hg} > 0$, we obtain $\frac{dh}{dg} > 0$. Also,

$$\frac{dh}{dt} = -\frac{-u_c\left(\frac{f_h-1}{p(Q)^2}\right)\frac{dp^c}{dt}-u_{cc}\left(\frac{f_h-1}{p(Q)}\right)\frac{c}{p(Q)}\frac{dp^c}{dt}}{u_c f_{hh}}. \tag{A2}$$

Since $f_h - 1 = 0$ from (6), the numerator of (A2) is zero. Thus, there is no effect of *t* on *h*.

To determine the effect of *g* and *t* on *c*, first recall that

$$c = \frac{f(h,g)-h}{p(Q)}. \tag{A3}$$

The effect of *g* on consumption is

$$\frac{dc}{dg} = \frac{f_g(h,g)+(f_h-1)\frac{dh}{dg}}{p(Q)} = \frac{f_g(h,g)}{p(Q)}, \tag{A4}$$

because $f_h - 1 = 0$ from (6). Thus $\frac{dc}{dg} > 0$. This illustrates the effect of *g* on consumption through income only and does not consider the effect through environmental regulations. The effect of *t* on consumption is such that:

$$\frac{dc}{dt} = -\frac{f(h,g)-h}{p(Q)^2}\frac{\partial p}{\partial t} + \frac{(f_h-1)\frac{dh}{dt}}{p(Q)} = -\frac{(f(h,g)-h)}{p(Q)^2}\frac{\partial p}{\partial t}. \tag{A5}$$

Recall that $f(h,g) - h = cp$ from (A3) and $\frac{\partial p}{\partial t} > 0$, thus $\frac{dc}{dt} < 0$.

To determine the effect of *g* and *t* on *s*, first recall that consumer surplus is defined as $s = u(c) - p(Q)c$. The impact of *g* on consumer surplus is

$$\frac{ds}{dg} = u_c\frac{dc}{dg} - p(Q)\frac{dc}{dg} = \left(u_c - p(Q)\right)\frac{dc}{dg}. \tag{A6}$$

One of the first order conditions from the household's problem is $\frac{u_c}{p(Q)} = \lambda$, where $\lambda > 0$ is the marginal utility of income. Substituting this condition into (A6) and since $\frac{dc}{dg} > 0$, it follows that $\frac{ds}{dg} > 0 \Leftrightarrow p(Q)(\lambda - 1)$. This condition only holds if $\frac{u_c{}^*}{p(Q)} > 1$, which means that consumers will never purchase goods that are priced higher than their willingness to pay ($u_c > p(Q)$).

The impact of tax of consumer surplus is

$$\frac{ds}{dt} = u_c \frac{dc}{dt} - p(Q)\frac{dc}{dt} - c\frac{\partial p}{\partial t} = \left(u_c - p(Q)\right)\frac{dc}{dt} - c\frac{\partial p}{\partial t}. \tag{A7}$$

Given (A5), along with the fact that $\frac{\partial p}{\partial t} > 0$, we find $\frac{ds}{dt} < 0$.

Proof of Lemma 2

First, we determine the effect of *x* on *t* by totally differentiating (10),

$$\frac{dt}{dx} = -\frac{G_{tx}}{G_{tt}} = -\frac{\alpha(t-\theta)m\frac{d^2q(x+k^*,g)}{dtdx} - mq_x}{G_{tt}}, \tag{A8}$$

where $G_{tt} < 0$ from concavity. Also, $\frac{d^2q(x+k^*,g)}{dtdx} = q_{kx}\frac{dk}{dt} + q_k\frac{d^2k}{dtdx}$. Here, $\frac{dk}{dt} = \frac{q_k}{(p-t)q_{kk}}$ and $\frac{d^2k}{dtdx} = 0$. Since $q_{kx} = q_{xk} < 0$ and $q_{kk} < 0$, then $\frac{d^2q(x+k^*,g)}{dtdx} = q_{kx}\frac{q_k}{(p-t)q_{kk}} > 0$. Define the elasticity of substitution as $\varphi^{k,x} \equiv \frac{q_k q_x}{q q_{kx}}$. The resulting necessary condition for (A8) to be negative is $G_{tx} < 0$, which occurs when, $\frac{(t-\gamma\theta)\alpha}{(p-t)}\frac{q_k q_k}{q q_{kk}} \leq \frac{q_k q_x}{q q_{kx}} \equiv \varphi^{k,x}$. This will always hold since *k* and *x* are perfect substitutes, leading to $\varphi^{k,x} \to \infty$, therefore $\frac{dt}{dx} < 0$.

To determine the effect *g* on *t*, we totally differentiate (10),

$$\frac{dt}{dg} = -\frac{G_{tg}}{G_{tt}} = -\frac{\alpha\left((t-\theta)m\frac{d^2q(x+k^*,g)}{dtdg} + n\frac{d^2s}{dtdg}\right) - mq_g}{G_{tt}}. \tag{A9}$$

Similar to the previous equation, the sign hinges on the numerator. The first term is

$\frac{d^2q(x+k^*,g)}{dtdg} = q_{kg}\frac{dk}{dt} + q_k\frac{d^2k}{dtdg}$. Here, $\frac{dk}{dt} = \frac{q_k}{(p-t)q_{kk}}$ and $\frac{d^2k}{dtdg} = 0$. Since $q_{kg} = q_{gk} > 0$ and $q_{kk} < 0$, then $q_{kg}\frac{q_k}{(p-t)q_{kk}} < 0$. This means that the first term is positive because $t < \gamma\theta$. The second term is $\frac{d^2s}{dtdg} = \left(u_c - p(Q)\right)\frac{d^2c}{dgdt} + \left(u_{cc}\frac{dc}{dt} - \frac{\partial p}{\partial t}\right)\frac{dc}{dg}$. Here, $\frac{d^2c}{dgdt} = -\frac{af_g(h,g)}{p(Q)}\frac{\partial p}{\partial t} = -\frac{dc}{dg}\frac{1}{p}\frac{\partial p}{\partial t} < 0$. Substituting $\frac{d^2c}{dgdt}$ into $\frac{d^2s}{dtdg}$ and simplifying yields, $\frac{d^2s}{dtdg} = \frac{1}{p}\frac{dc}{dg}\frac{\partial p}{\partial t}(-u_{cc}c - u_c)$. Therefore, as long as $-u_{cc}c - u_c > 0$ or $\frac{-u_{cc}c}{u_c} > 1$, which in empirical estimates holds, we will have $\frac{d^2s}{dtdg} > 0$. Finally, the last term, $-mq_x$, is negative.

A necessary condition for $G_{tg} > 0$ is that the first two terms outweigh the last term. A sufficient condition would be if the third term is outweighed by the first term. We derive the following condition, $(t-\theta)\alpha q_{kg}\frac{q_k}{(p-t)q_{kk}} - q_g \geq 0$. Re-arranging and defining the elasticity of substitution, $\varphi^{k,g} \equiv \frac{q_k q_g}{q q_{kg}}$, we obtain the condition $\frac{(t-\theta)\alpha}{(p-t)}\frac{q_k q_k}{q q_{kk}} \geq \varphi^{k,g}$. This means that a sufficient condition is that there is an upper bound for the substitutability between *k* and *g* in the production of the good causing the consumption pollutant. The less substitutability between *k* and *g*, the more likely we will have $G_{tg} > 0$ and $\frac{dt}{dg} > 0$.

Proof of Proposition 2

Taking the derivative of (A3) with respect to *g* and considering the effect of *g* on income and price, we find

$$\frac{dc^*}{dg} = \frac{f_g + (f_h - 1)\frac{dh}{dg}}{p(Q)} - \frac{f(h,g) - h}{p(Q)^2}\frac{dp}{dQ}\frac{dQ}{dq}\left(q_t\frac{dq}{dt} + q_x\frac{dx}{dg} + q_g\right). \tag{A10}$$

Recall that $\frac{dQ}{dq} = m$ and $\frac{dx}{dg} = -1$ when *G* is fixed. Re-arranging terms and recognizing that $f_h - 1 = 0$, we arrive at

$$\frac{dc^*}{dg} = \frac{pf_g - (f(h,g)-h)\frac{dp}{dQ}m\left(q_t\frac{dq}{dt}+q_x\frac{dx}{dg}+q_g\right)}{p(Q)^2}. \tag{A11}$$

The sign of the numerator determines the sign of (A11). Divide the numerator and denominator by $p(f(h,g)-h)$. Then recognize that $f(h,g)-h = cp$ and at equilibrium demand equals supply such that $mC=Q$. Finally define $\epsilon \equiv \frac{dQ}{dp}\frac{p}{Q}$. We arrive at

$$\frac{dc^*}{dg} = \frac{pf_g - \frac{1}{\epsilon}\left(q_t\frac{dt}{dg}-q_x+q_g\right)}{\frac{p(Q)^2}{p(f(h,g)-h)}}. \tag{A12}$$

Thus $\frac{dc^*}{dg} < 0$ when $pf_g < \frac{1}{\epsilon}\left(q_t\frac{dt}{dg} - q_x + q_g\right)$.

Proof of Proposition 3

Taking the derivative of (11) with respect to α, we derive

$$\frac{d^2Z}{dgd\alpha} = n\gamma\left(\frac{dc}{dt}\frac{d^2t}{dgd\alpha}\right) < 0. \tag{A13}$$

For the term to be negative, we need $\frac{d^2t}{dgd\alpha} > 0$. Using (A9),

$$\frac{d^2t}{dgd\alpha} = -\frac{\left((t-\gamma\theta)m\frac{d^2q(x+k^*,g)}{dtdg}+n\frac{d^2s\left(t,w,p^h,g,a\right)}{dtdg}\right)}{G_{tt}}. \tag{A14}$$

We have already proven that the numerator of (A14) is negative from the proof in Lemma 2 as long as $\frac{-u_{cc}c}{u_c} > 1$.

Appendix B

Appendix B1. *Country samples*

CO 26 countries

Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Costa Rica, Denmark, El Salvador, Estonia, Finland, Germany, Greece, Hungary, Latvia, Lithuania, Mexico, New Zealand, Republic of Korea, Sweden, Switzerland, United Kingdom, United States, Uruguay

NO_2 33 countries

Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Costa Rica, Croatia, Denmark, El Salvador, Estonia, Finland, Germany, Greece, Hungary, India, Latvia, Lithuania, Mexico, New Zealand, Panama, Republic of Korea, Sweden, Switzerland, Thailand, Turkey, United Kingdom, United States, Uruguay, Venezuela

Income 95 countries

Algeria, Argentina, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Belarus, Belgium, Bhutan, Bolivia, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cameroon, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Egypt, Arab Rep., El Salvador, Estonia, Ethiopia, Finland, France, Georgia, Germany, Greece, Guatemala, Hungary, India, Indonesia, Iran, Islamic Rep., Ireland, Israel, Italy, Jamaica, Jordan, Kazakhstan, Kenya, Korea, Rep., Kyrgyz Republic, Latvia, Lebanon, Lesotho, Lithuania, Madagascar, Malaysia, Mali, Mauritius, Mexico, Moldova, Morocco, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Russian Federation, Senegal, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Thailand, Trinidad and Tobago, Tunisia, Turkey, Uganda, Ukraine, United Kingdom, United States, Uruguay, Venezuela, RB, Zambia

Appendix B2. *Variable description and source*

Variable	Description	Source
Nitrogen Dioxide (NO_2)	NO_2 concentrations, micrograms per cubic meter	GEMS
Carbon Monoxide (CO)	CO concentrations, micrograms per cubic meter	GEMS
Share of Government Expenditures on Public Goods	Expenditures on public goods in total government expenditures include: Education, Health, Social security, Transport, Communication, Public order and safety, Housing and community amenities, Environmental Protection, Religion and Culture	Our own calculations using Government Financial Statistics from the International Monetary Fund, Asian Development Bank, Country data
Share of Government consumption Expenditure over GDP		Penn World Tables (2006)
Share of Investment over GDP		Penn World Tables (2006)
Household final consumption expenditure per capita - 3 year moving average (2000 US$)	Market value of all goods and services purchased by households imputed rents.	World Development Indicators, World Bank
Total population		WDI
Agriculture, value added (% of GDP)		WDI
Manufacturing, value added (% of GDP)	Manufacturing, value added excludes mining, gas, water, electricity	WDI
Trade (imports plus exports) over GDP		WDI
Dummy freedom of press	1 if print media is considered free	www.freedomhouse.org
Polity 2 Index of Democracy	Indicates how democratic a country is ranging from -10 to 10	Polity IV
Years of democratic stability	Square root of Durability of Polity if Polity 2>0	Polity IV
City center	1 if monitoring site located in city center	GEMS
Other Urban Areas	1 if monitoring site located in urban area (excluding city center)	GEMS
Rural Areas	1 if monitoring site located in rural area	GEMS

Appendix B3. *Summary statistics*

Variable	Mean	Std. Dev.	Min	Max
Nitrogen Dioxide (NO_2)	42.18	24.18	1.00	251.08
Carbon Monoxide (CO)	2041	2348	10	18370
Log share of public goods, lagged	-0.66	0.32	-1.55	-0.13
Log share of government consumption, lagged	-1.60	0.39	-2.49	-0.96
Log Share of investment, lagged	-1.74	0.46	-3.53	-0.82
3 year moving average of Household Final Consumption	6,330	5,392	158	22,223
Log of total population	1.96	1.08	0.20	3.48
Log of Agriculture, value added (% of GDP) lagged	3.03	0.22	2.21	3.56
Log of Manufacturing, value added (% of GDP) lagged (excludes mining, gas, water, electricity)	-0.84	0.61	-2.08	0.69
Log of Trade (imports plus exports) over GDP, lagged	18.07	1.88	14.14	20.94
Dummy free press	0.69	0.46	0.00	1.00
Polity index (indicates how democratic a country is) (-10,10)	7.38	4.15	-7.00	10.00
Years of democratic stability	4.80	3.81	0.00	13.78
City center	0.29	0.46	0.00	1.00
Other Urban Areas	0.23	0.42	0.00	1.00
Rural Areas	0.00	0.03	0.00	1.00

Note: Summary statistics for NO_2 and CO covariates are based on the NO_2 and CO samples, respectively.