Carrot and Stick: Collateral Effects of Green Public Policy

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Abstract

Green public policy goals can be met by a wide range of instruments, which invites a comprehensive analysis of their direct and collateral effects. This study is focused on the two regulatory instruments, emission taxes and green public procurement, which differ in compulsion and type of impact. We provide a general equilibrium analysis in order to investigate welfare and environmental outcomes of the both green policies in autarky and upon trade integration. The model uses two sources of heterogeneity - across firms in regard to their productivity and across countries in regard to the type and stringency of environmental policy. We show that while taxation yields more quantitatively significant social and ecological effects, green public procurement is more efficient in environmental damage reduction per unit of welfare loss. Exposure to international trade delivers inconclusive results when countries with lower taxation and higher eco-bias in government purchases face increasing emissions and welfare. Countries with higher taxation and lower eco-bias in government purchases experience decreasing emissions and welfare. Meanwhile, trade integration unambiguously favours trading partners if they introduce identical taxation or green public procurement programmes.

Keywords: green public procurement, environmental taxation, green public policy, heterogeneous firms.

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1 Introduction

Current rise of green public policy has its roots in the 1960s with the publication of *Silent Spring* by Rachel Carson[1] and the subsequent growth of ecological concerns all over the world, bringing environmental issues to the global agenda[2]. Since then environmental policy has been developed in different dimensions such as predominantly targeted areas, actors, ranges of effects and instruments, causing intense debates on their efficiency, which requires comprehensive analysis of their direct and collateral outcomes.

Our paper aims to compare the welfare and environmental impact of two widely implemented environmental policy instruments, emissions taxes (*stick*) and green public procurement (GPP, *carrot*). The choice of regulatory instruments is based on the following reasoning. First, they represent two alternative approaches to regulation that feature mandatory *vs.* voluntary participation and direct *vs.* indirect influence. Thus, emission tax is a mandatory instrument that targets negative environmental effects directly, while GPP offers producers a voluntary opportunity to affect the greening of the production process through demand changes[3]. Second, we aim to investigate the effect of GPP relative to taxation due to the growing expectations of the former as an efficient and desirable policy instrument. Since public purchasing accounts for 12% GDP in OECD countries (OECD, 2011) and 16% of GDP within the European Union (EC, 2008), green public procurement has a significant potential to influence markets and industries. Meanwhile, theoretical research of its consequences challenges this point of view emphasising the sources of possible non-efficiency of the GPP programmes[4]. In order to enrich the analysis we provide an alternative approach to disclose the channels of GPP policy influence, both direct and collateral, that have

[1]Carson, Rachel. *Silent Spring.* Houghton Mifflin Company, 1962.

[2]World-wide discussion of ecological threats started in the beginning of the 1970s at the *Paris Summit of the European Economic Community* (1972) and the *UN Conference on the Human Environment* in Stockholm (1972).

[3]Meanwhile, Lundberg and Marklund (2013) also stress the command-and-control nature of green purchasing due to the direct criteria set by the government while defining green products. Therefore, one can think of GPP as a mixed voluntary-mandatory regulatory instrument.

[4]See Section 3 for the overview of the relevant literature.

not been addressed before.

Green public policy yields a wide range of outcomes including such straightforward effects as greening the market and emissions decline as well as such possible secondary effects as environmentally-friendly technological progress. To focus on the primary effects of the chosen policy instruments we ignore any possible impact of public policy on the decisions made by economic agents beyond the immediate reaction to the regulation. Thus, we assume no environmental bias in consumer and producer behaviour implying the government to be the only source of ecological concerns. We particularly explore the transformation effect of regulation when producers are incentivised to green the production process within the current technological framework.[5]

Another keystone of our approach relies on the magnitude of government green purchasing. Data shows that the public procurement shares vary conditionally on the type of products[6]. For example, one would expect nearly monopolistic power of the government in the defence industry. Meanwhile, in a wide range of industries such as textile and apparel, office equipment, food products, *etc.*, the degree of public intervention is much smaller and comparable to other consumers in the market. The present paper ignores the monopoly case focusing on the monopolistically competitive nature of public and private agents' behaviour.

Our research compares the effects of green taxation and GPP on the "green intensity" of the economies and how they evolve with trade liberalisation in the general equilibrium setting. The model features monopolistic competition, heterogeneous firms, tax incentives towards green technology,

[5]The literature emphasises two principal dimensions of GPP policy, transformation and substitution. See Marron (1997), Lundberg et al. (2015), and Section 3 of the present paper for the details.

[6]See, for example, Trionfetti (2001), Marron (2003), Brülhart and Trionfetti (2004). Renda et al. (2012) report the heterogeneity of product groups subject to green procurement. At least one EU core criterion is used while purchasing office IT equipment and construction services (more than 60% of contracts). On the opposite side of the spectrum are food products and catering services (48%) and electricity (23%). Meanwhile, any green criteria regardless of their compliance with the EU rules are the most widely used while purchasing office and IT equipment, transport, and cleaning services and products (more than 60%). The lowest share of green contracts are in electricity, food products and catering services (less than 50%) .

and green-biased government demand in the form that most closely represent the current normative framework; that is, a minimum "green input requirement".

The analysis shows the main and collateral effects of environmental regulation based on resources redistribution across industries and productivity changes. The results can be aggregated in three main strands.

First, the model illustrates self-selection of producers when the most productive ones aim for cleaner technologies while the less productive find it optimal to preserve the initial status.

The second set of results shows the effects of green policy under autarky. Thus, the expansion of both instruments decreases emissions and utility while the absolute changes are more significant with environmental taxation. At the same time, green public procurement is relatively more efficient, leading to higher emissions reduction per unit of welfare loss. The model also illustrates the collateral effects of environmental policy in autarky that refer to firms' productivity dynamics. Green policy expansion toughens the competition, forcing the most efficient firms to implement eco-friendly technologies, and the least efficient to leave the market[7].

Finally, in the open economy setting we show the ambiguity of welfare and environmental outcomes of trade integration across countries which introduce green public regulation. We show that relatively low taxes and significant GPP policy incur higher emissions and higher welfare[8], while relatively high taxes and modest GPP policy deliver the opposite results. The only possible "win-win" situations occur when identical countries opt for identical tax or GPP policy which leads to an increase in welfare and no changes or decrease in emissions. Therefore, the model predicts the harmonisation of green public policies to be beneficial for all trading countries. The model also illustrates collateral open economy productivity effects stemming from the type of green public policy. We show that while taxes do not influence market

[7]The latter result is conditional on the emission intensity of production process. We report here the outcome obtained under a more general assumption when the production process is relatively emission efficient. See Section 5 for the details.

[8]Throughout the paper we consider "pure" welfare without accounting for environmental damage.

efficiency, GPP generates additional exit/entry dynamics for firms: exposure to trade enlarges the non-environmentally friendly sector of the market due to the tougher competition in the environmentally-friendly sector and to the reallocation of production factors.

This study aims to enrich the theoretical research on GPP which remains scant despite the growing GPP implementation all over the world. Remarkable exceptions are the studies by Marron (1997), Lundberg and Marklund (2013), Lundberg and Marklund (2011), and Lundberg et al. (2015).[9] We contribute to the literature by investigating the impact of GPP within the model that incurs two types of heterogeneity: across countries in the stringency and type of environmental policy and across producers in their productivity. To the best of our knowledge, this has not been done before. This framework is applicable both to closed and open economy settings. Our approach is also in line with two other strands of literature on the environmental impact of trade integration with heterogeneous firms (see, for example, Batrakova and Davies (2012), Cui et al. (2012), Kreickemeier and Richter (2014), Forslid et al. (2015)), and on the impact of public procurement on the market outcomes (see, for example, Trionfetti (2001) and Brülhart and Trionfetti (2004)).

The rest of the paper is organised as follows. Section 2 introduces environmental taxation and GPP as green public policy instruments. Section 3 overviews the literature on GPP. Section 4 introduces the model. Section 5 investigates the outcomes of different policy scenarios both in autarky and upon trade integration. And Section 6 discusses the results and concludes.

2 Environmental Policy Instruments

Green policy toolkit contains numerous differentiated instruments reflecting the complexity of arising environmental problems and corresponding structure of environmental governance. The regulatory approaches can be grouped in three main categories: *direct or command-and-control regulation*

[9] See Section 3 for the literature review.

(*e.g.*, technological standards and certification), *market-based instruments* (*e.g.*, emission quotas and taxes, subsidies, tradable permits), and *disclosing approaches* (*e.g.*, environmental labelling and promotional programmes) (Marron, 2003). These instruments differ in several ways, including targeted goals, stringency, compulsion (mandatory or voluntary), or type of impact (direct or indirect). In general, they can be predominantly *prohibitive* to impose a burden on economic agents or *incentivising* to encourage them to improve the production process (Albrizio et al., 2014).

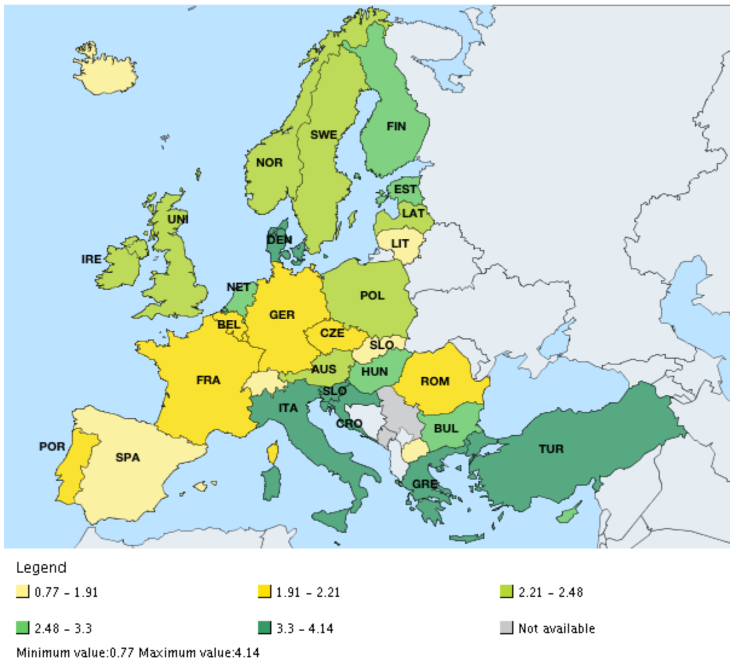
Environmental Taxation. The European Commission defines an environmental tax as "*a tax whose tax base is a physical unit (or a proxy of a physical unit) of something that has a proven, specific negative impact on the environment, and which is identified in ESA95*[10] *as a tax*"[11]. It is a widely used market-based green policy instrument directly addressing the market failure of ignoring the negative ecological impact of the production process. The first green tax was introduced in 1959 in French water legislation, and in 1971 in the Netherlands and Germany to address the effluent control (McEldowney and Salter, 2015). In the 1970s the US started to develop market-based green policy by introducing taxes on gas-guzzling cars (1978) and chemicals (1980) (Milne, 2011). Since then environmental taxes have been widely represented all over the world accounting for 5.07% of the OECD total tax revenue (OECD, 2017).

The European Commission puts environmental taxes into four main categories: energy taxes (including fuel for transport) - 77% of EU-28 environmental tax revenues; transport taxes (excluding fuel for transport) - 20%; pollution and resources taxes - 4% (EU, 2016). Overall they account for 2.4% of the EU-28's GDP varying from 0.77% in Liechtenstein to 4.14% in Denmark (Figure 1, Eurostat, 2013).

[10]ESA95 abbreviates the European system of national and regional accounts.

[11]Regulation (EU) No 691/2011 of the European Parliament and of the Council of 6 July 2011 on European environmental economic accounts, 16/06/2014.

Figure 1: *Environmental Tax Revenues: percentage of GDP (source - Eurostat, 2013)*



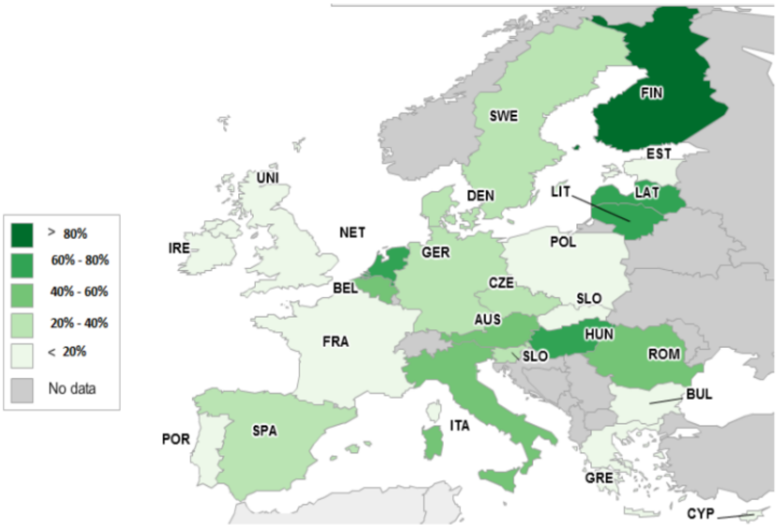
Green Public Procurement. Green Public Procurement (GPP) is defined by the European Commission as "*a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured*"[12]. The majority of GPP practices were launched in the early 1990s, meanwhile, such pioneering countries as Germany, Austria and Japan introduced the first initiatives up to 15 years earlier[13]. Often GPP activities coincide with the establishment of eco-labels as a voluntary environmental policy tool.[14]

[12]COM(2008) 400 *Public procurement for a better environment*, pp.3.1.

[13]Brief retrospective analysis of GPP's development is provided, for example, by Ochoa et al. (2003).

[14]Because GPP development is an issue of recent interest, the corresponding data on its implementation is rare and incomplete. One of the exceptions is the *Collection of statistical information on Green Public Procurement in the EU* (PricewaterhouseCoopers and Ecofys, 2009) that presents the impact of GPP instruments in Austria, Denmark, Finland, Germany, the Netherlands, Sweden, and the UK in 2006/07.

Figure 2: *Uptake of GPP (based on the EU GPP criteria set) in the EU27 (share of all contracts in 2009/10 by value for 10 product groups) (Renda et al., 2012)*



The data is obtained from a target survey of authorities for the ten product groups: cleaning products and services; construction; electricity; catering services and food products; gardening services and products; office IT equipment; copying and graphic paper; textiles; transport; and furniture.

OECD countries introduced the idea of the public procurement environmental performance to the global agenda in 2002.[15] Within the EU the importance of GPP was stressed in 2003 when the member states were urged to adopt national plans for greening the public purchasing policy by the end of 2006.[16] In 2008 the European Commission adjusted the target calling for the increase of GPP compliant with the EU core criteria[17] to the 50% of all public procurement. The monitoring accomplished in 2012 shows that the target has not been reached. Nevertheless, 55% of the contracts signed by

[15]See the OECD *Recommendation of the Council on Improving the Environmental Performance of Public Procurement*, C(2002)3, 23 January 2002.

[16]See the European Commission Communication *Integrated Product Policy - Building on Environmental Life-Cycle Thinking*, COM/2003/0302.

[17]There are two types of criteria within the EU, the core and the comprehensive criterion. The core criterion addresses the key environmental impacts and implies a minimum additional verification while the comprehensive criterion identifies the best environmentally friendly products. Thus, the former criteria requires relatively lower spendings to the production process adjustment in comparison with the latter.

European public authorities in 2009/10 included at least one EU core GPP criterion. More than 80% of public contracts were green in Sweden, Denmark, the Netherlands, and Belgium. And Finland was the ultimate leader by value (more than 80% of all signed contracts value)[18]. The results also show that for a wide range of industries[19] 38% of the total public procurement value in the European Union is related to green purchases based on EU, national, regional, local, or any other environmentally friendly criterion (Figure 2, Renda et al. (2012)).

3 Literature Review

Upon implementation of the GPP programmes certain obstacles come to light such as relatively higher prices of green goods and services, lack of clear environmental standards, and absence of monitoring and evaluation mechanisms (OECD, 2015). These issues are of particular importance due to the risk of sacrificing the major goals of public procurement: the support of environmental and sustainable development may contradict the public procurement "value-for-money" principle. Nevertheless, policymakers generally consider GPP as a driver for greening the production process and subsequent development of clean technologies and environmental degradation reduction (EC, 2016). They also stress the "leading-the-way" impact: GPP can raise environmental concerns in the society strengthening green bias in preferences (Oosterhuis et al. (1996), Marron (2003)).

Practical implementation of GPP is well-represented in the literature. See, for example, studies on *China* - Geng and Doberstein (2008), Ho et al. (2010), Qiao and Wang (2011), Zhu et al. (2013), *Denmark* - Mosgaard et al. (2013), *Finnland* - Parikka-Alhola (2008), *Hungary* - Valkó and Kiss (2005), *Italy* - Cerutti et al. (2016), Testa et al. (2012), Testa et al. (2016), *Japan* - Ho et al. (2010), *Norway* - Fet et al. (2011), Igarashi et al. (2015)), Michelsen

[18]For the particular examples of GPP implementation see, for example, OECD (2015), EC (2012).

[19]Cleaning products and services; construction; electricity; catering services and food products; gardening services and products; office IT equipment; copying and graphic paper; textiles; transport; and furniture.

and de Boer (2009), *South Korea* - Ho et al. (2010), *Sweden* - Arvidsson and Stage (2012), Lundberg et al. (2015), Parikka-Alhola (2008), *Taiwan* - Ho et al. (2010), Tsai (2017), *Thailand* - Ho et al. (2010), the *USA* - Simcoe and Toffel (2014). However, its theoretical analysis remains rather scant. A few notable exceptions are the studies by Marron (1997) and Lundberg et al. (2015) who investigate GPP in partial equilibrium settings assuming a range of different market structures, from perfect competition to oligopoly, and different degrees of substitution between brown and green varieties (Lundberg et al. (2015) also introduce a competitive tendering process), and papers by Lundberg and Marklund (2011) and Lundberg and Marklund (2013) who focus on the role of awards in GPP contracts within the auction theory framework.

In general, GPP is considered as a substitution (Marron, 1997) and/or a transformation (Lundberg et al., 2015) policy. Substitution policy urges buyers to choose environmentally cleaner (green) over environmentally dirtier (brown) varieties, and transformation policy incentivises producers to "green" the production process. Lundberg and Marklund (2013) state that substitution policy can be considered as a special case of the transformation policy.

The findings of the theoretical analysis of GPP are rather dubious. The key concerns can be structured in three general sets of findings. First, the literature argues that GPP impact should be judged not only on the basis of government but also private purchases. Private market responses to GPP can offset, amplify or sterilise government purchases conditional to the marginal cost changes that are often overlooked upon implementation. The second strand of concerns stresses the fact that public procurement can alter both the size of the green sector and of the whole market. In the latter case it may lead to the emissions growth ruining the main goal of the green public policy. And, third, Lundberg and Marklund (2013) provide evidence of the cost-inefficiency of GPP as an emissions reducing instrument.

Overall, the existing analysis shows that the impact of GPP heavily depends on market structure and on government market power as well as on consumer attitudes towards brown and green varieties. It stresses the limitations of the GPP efficiency challenging the common public attitude to consider government green purchasing as an efficient and desirable public policy instrument.

In order to contribute to the current discourse, we designed a general equilibrium model that explores new channels of green policy impact aiming to compare GPP with a more traditional environmental instrument - taxation.

4 The Model

The economy is comprised of two countries indexed by i $(i = F, H)$, three sectors, the manufacturing sector, $\mathcal{Z}$, the government sector, $\mathcal{G}$, and the service sector, $\mathcal{S}$, and one factor of production, labor, whose supply is constant and equal to L_i.

The service sector is an outside good and serves as a *numéraire*. As such, $\mathcal{S}$ is produced by perfectly competitive firms that use a constant-returns-to-scale technology which requires a unit of labor input per unit of output. Sector $\mathcal{S}$ is assumed to be costlessly traded and big enough to absorb all changes in demand for labor emanating from the monopolistic competitive sector. Accordingly, the model assumes both countries to produce $\mathcal{S}$ which assures the price of $\mathcal{S}$ is the same across countries. We normalise it to one. This setting yields equal wages that take the value of one.

Good $\mathcal{Z}$ is produced in many varieties in a monopolistically competitive market by firms using an increasing-returns-to-scale technology that requires fixed and variable labor input. Any variety of $\mathcal{Z}$ is traded internationally at an iceberg cost by which for one unit sent only a fraction $\tau \in (0, 1]$ arrives. Varieties may be produced using a green or a brown technology which differ by fixed and marginal labor input. The marginal labor input not only differs by technology but may also differ across firms within a technology since it has a random component. The technology is observed by the government but not by consumers. Let M_i, $M_{br,i}$, and $M_{gr,i}$ denote, respectively, the set of all varieties, brown varieties and green varieties available to consumers in country i; obviously $M_i = M_{br,i} + M_{gr,i}$ and $M_{br,i} \cap M_{gr,i} = \emptyset$.

Households. Households preferences are described by a Cobb-Douglas utility function defined over $\mathcal{S}$ and $\mathcal{Z}$: $U_i = \mathcal{Z}_i^{\mu}\mathcal{S}_i^{1-\mu}$ with $\mu \in (0,1)$, and where $\mathcal{Z}_i$ is a CES aggregate of all varieties (green and brown).[20] The elasticity of substitution among any pair of varieties is $\sigma > 1$. National income is L_i, and households are taxed at a rate T, same in both countries. Utility maximisation under budget constraint and aggregation over households yields the demand emanating from domestic and foreign residents for any variety m of the manufacturing good produced in i:

$$d_i^h = p_{ii}^{-\sigma}\mathcal{B}_i^h + p_{ij}^{-\sigma}\mathcal{B}_j^h \qquad \forall m \in \Theta_i, \quad i,j = H,F, \quad i \neq j \tag{1}$$

where in d_i^h the superscript ^{h} refers to household demand (distinct from government demand), the subscript $_i$ refers to the country where the variety is produced, $\mathcal{B}_i^h = P_i^{\sigma-1}\mu I_i^h$ is a household demand shifter, P_i denotes the CES price index relevant for households in i, and p_{ii} is the price a firm in i charges to residents in i, and p_{ij} is the price a firm in i charges to residents in j; I_i^h represents national disposable income; the variety index m is omitted in order not to burden the notation but obviously the price of different varieties may differ because marginal cost may differ due to technology and/or to the random component of marginal labor input. Indirect utility is represented as $V_i = I_i^h P_i^{-\mu}$.

Technologies. Production of any variety of $\mathcal{Z}$ requires a fixed input and a constant marginal input per unit of output. Firms may choose between a green technology and a brown technology. The green technology requires higher fixed and marginal labor inputs than the brown technology. Furthermore, even within a technology (brown or green) the marginal labor input is the realisation of productivity represented by a random variable ϕ whose

[20] Government services do not enter the consumers utility function due to the assumption of the exogenous tax rate that is not necessarily optimal. The model can also be built in the spirit of the public finance literature allowing for the optimal taxation determined endogenously. Meanwhile, this approach combined with the consumers eco-ignorance requires zero green public procurement bias. Thus, we eliminate this additional welfare effect in order to focus on the green public policy impact rather than on discovering the optimal policy design.

cumulative distribution function is $\Omega(\phi)$ defined in the set $[\phi_0, \infty)$. To be specific the labor input per q units of output is $l_{br} = F_{br} + q_{br}/\phi$ for brown firms and $l_{gr} = F_{gr} + cq_{gr}/\phi$ for green firms where $F_{gr} > F_{br}$ and $c > 1$. Naturally, green and brown technology differ also in terms of emission per unit of output which, for a brown and a green firm respectively are $\varepsilon_{br} = (\phi)^{-\alpha}$ and $\varepsilon_{gr} = \delta(\phi)^{-\alpha}$ where $\alpha \geq 0$ captures the assumption that more productive firms pollute less and also allows for no relationship between productivity and emission intensity[21], and $\delta \in (0, 1)$ captures the fact that the green technology is less polluting.

Governments. Governments produce a general service $\mathcal{G}$ by inputting the CES aggregate $\mathcal{Z}$ and labor in a Cobb-Douglas production function: $\mathcal{G}_i = \mathcal{Z}_i^{\mu} L_i^{1-\mu}$. The cost shares are the same as expenditure shares; this is made for notational convenience and has no qualitative consequences on the results. We consider two distinct green policy instruments: taxation and public procurement.

- **Taxation, or "Stick" policy.** Government can introduce a carbon tax $t_i > 0$ that represents a fee per one unit of emissions. Collected tax payments are transferred as a subsidy to consumers.
- **Green Public Procurement, or "Carrot" policy.** Government can implement a policy by which a fraction $\gamma_i \in (0, 1]$ of total government purchases is reserved for green products.[22] The remaining fraction is spent on all varieties regardless of whether they are green or brown. As a consequence, two distinct demand functions emanate

[21] The assumption of a negative relationship between productivity and pollution is based on the empirical findings of Batrakova and Davies (2012) (data on Ireland), Cole et al. (2008) (data on China), Forslid et al. (2015) (data on Sweden), Cui et al. (2012) and Scott Holladay (2016) (data on the US). The assumption of no relationship between productivity and emission intensity is supported, for example, by the empirical findings of Rodrigue and Soumonni (2014) (data on Indonesia).

[22] We introduce GPP policy in the form of a set-aside target spendings. Meanwhile, another common way of the green purchases implementation can be shaped as price preferences when the government sets the allowed mark-up for cleaner products.

from each government:

$$\begin{aligned} d_i^g &= p_{ii}^{-\sigma}\mathcal{B}_i^g + p_{ij}^{-\sigma}\mathcal{B}_j^g \qquad \forall m \in M_i, \quad i,j = H,F; i \neq j. \quad (2) \\ d_{gr,i}^g &= p_{ii}^{-\sigma}\mathcal{B}_{gr,i}^g + p_{ij}^{-\sigma}\mathcal{B}_{gr,j}^g \quad \forall m \in M_{gr,i}, \quad i,j = H,F; i \neq j. \quad (3) \end{aligned}$$

where $\mathcal{B}_i^g = P_i^{\sigma-1}(1-\gamma)\mu TL_i$ and $\mathcal{B}_{gr,i}^g = P_{gr,i}^{\sigma-1}\gamma\mu TL_i$ are government demand shifters such that P_i and $P_{gr,i}$ correspond to CES price indexes that contain all and only green varieties available in the market respectively.

Pricing. Firms are profit maximizers. The demand addressed to brown and green firms is, respectively,

$$\begin{aligned} q_{br,i} &= d_i^h + d_i^g \qquad \forall m \in M_{br,i}, \qquad i,j = H,F; i \neq j. \qquad (4) \\ q_{gr,i} &= d_i^h + d_i^g + d_{gr,i}^g \quad \forall m \in M_{gr,i}, \qquad i,j = H,F; i \neq j. \qquad (5) \end{aligned}$$

Profits are $\pi_{br,i} = (p - t_i\varepsilon_{br,i})q_{br,i} - l_{br}$ and $\pi_{gr,i} = (p - t_i\varepsilon_{gr,i})q_{gr,i} - l_{gr}$, therefore, the profit maximizing prices are

$$p_{br,ii}(\phi) = \frac{\sigma}{\sigma-1}\left(\frac{1}{\phi} + \frac{t_i}{\phi^\alpha}\right), \qquad p_{br,ij} = \frac{p_{br,ii}}{\tau} \qquad (6)$$

$$p_{gr,ii}(\phi) = \frac{\sigma}{\sigma-1}\left(\frac{c}{\phi} + \frac{t_i\delta}{\phi^\alpha}\right) \qquad p_{gr,ij} = \frac{p_{gr,ii}}{\tau}. \qquad (7)$$

The terms in parenthesis are the tax-inclusive marginal cost of the brown and green technologies, respectively.

Emissions. Emissions of a brown and a green firm are, respectively,

$$\mathcal{E}_{br,i} = \varepsilon_{br}q_{br,i} = \frac{q_{br,i}}{\phi^\alpha} \qquad (8)$$

$$\mathcal{E}_{gr,i} = \varepsilon_{gr}q_{gr,i} = \delta\frac{q_{gr,i}}{\phi^\alpha} \qquad (9)$$

Emissions depend on productivity through two opposite channels: a higher productivity corresponds to a higher output and, therefore, higher emissions but also to a lower emission per unit of output. We assume, as it seems reasonable, that the first channel dominates the second. Accordingly, we set the total derivatives of emission with respect to ϕ to be positive, which requires $\sigma \geq \alpha$.

Emission tax income is represented as

$$Tax_i = \int_{M_{br,i}} \mathcal{E}_{br,i} d\Omega(\varphi) + \int_{M_{gr,i}} \mathcal{E}_{gr,i} d\Omega(\varphi) \tag{10}$$

Accordingly, consumers disposable income $I_i^h = (1-T)L_i + Tax_i$.

Zero cut off profits and no-arbitrage condition. Revenue functions are $r_{br,i} = p_{br,ii} q_{br,i}$ and $r_{gr,i} = p_{gr,ii} q_{gr,i}$ and the profit functions are $\pi_{br,i} = r_{br,i}/\sigma - F_{br}$ and $\pi_{gr,i} = r_{gr,i}/\sigma - F_{gr}$. The zero cutoff profit condition defines the value of ϕ to which correspond zero profit for cutoff firms. Defining $\Delta\pi_i = \pi_{gr,i} - \pi_{br,i}$, we obtain $\lim_{\phi\to 0} \Delta\pi < 0$ and $\lim_{\phi\to\infty} \Delta\pi > 0$. Consequently, in a market where brown and green firms coexist, it is always the case that any brown firm is less productive than any green firm.[23] Therefore, the zero cutoff profit condition (ZCP) concerns only brown firms. Such condition, described in equation (11), defines the cutoff value of productivity denoted ϕ^*_{br}. The no-arbitrage condition (NAC) described in equation (12) defines the value of ϕ for which the profits of a brown firm and a green firm are equal. Such value, denoted ϕ^*_{gr}, is necessarily higher than ϕ^*_{br} since profits increase monotonically with ϕ.

$$\text{ZCP} \qquad \pi_{br,i}(\phi^*_{br,i}) = 0 \tag{11}$$

$$\text{NAC} \qquad \pi_{br,i}(\phi^*_{gr,i}) = \pi_{gr,i}(\phi^*_{gr,i}) \geq 0 \tag{12}$$

[23] "Single colour" equilibria where only brown or only green firms exist may arise in our model. We rule them out for the moment since they are less interesting and less reasonable.

Sales and profits. Applying equations (11)-(12) to the profit functions we obtain the cutoff revenues:

$$r_{br,i}(\phi^*_{br,i}) = \sigma F_{br}, \tag{13}$$
$$r_{gr,i}(\phi^*_{gr,i}) = r_{br,i}(\phi^*_{gr,i}) + \sigma(F_{gr} - F_{br}). \tag{14}$$

For any two firms with different productivity but using the same technology the relative sales depend only on the different realizations of ϕ. Thus, for two firms with realizations ϕ' and ϕ'' we have:

$$\frac{r_{br,i}(\phi')}{r_{br,i}(\phi'')} = \left(\frac{p_{br,ii}(\phi')}{p_{br,ii}(\phi'')}\right)^{1-\sigma} \quad \text{and} \quad \frac{r_{gr,i}(\phi')}{r_{gr,i}(\phi'')} = \left(\frac{p_{gr,ii}(\phi')}{p_{gr,ii}(\phi'')}\right)^{1-\sigma} \tag{15}$$

Applying (15) to the cut off firms and to any other firm we obtain firms sales:

$$r_{br,i}(\phi) = \left(\frac{p_{br,ii}(\phi)}{p_{br,ii}(\phi^*_{br,i})}\right)^{1-\sigma} \sigma F_{br} \tag{16}$$
$$r_{gr,i}(\phi) = \left(\frac{p_{gr,ii}(\phi)}{p_{gr,ii}(\phi^*_{gr,i})}\right)^{1-\sigma} \left[r_{br,i}(\phi^*_{gr,i}) + \sigma(F_{gr} - F_{br})\right] \tag{17}$$

Aggregation Average (or expected) values are obtained by integration of all firms in the set to which the firm belongs and aggregate values are obtained by multiplying the average by the mass. Allpowered average will be denoted by a tilde and regular average by an over-line. Appendix 7.1 provides the details of aggregation.

Free entry and exit. Free entry and exit assures that in equilibrium the expected profit prior to entry is equal to the entry cost F_e:

$$\left[1 - \Omega(\phi^*_{gr,i})\right] \overline{\pi}_{gr,i} + \left[\Omega(\phi^*_{gr,i}) - \Omega(\phi^*_{br,i})\right] \overline{\pi}_{br,i} = F_e \tag{18}$$

Masses of firms. Let's denote by $M_{e,i}$ a mass of potential entrants to the market of good $\mathcal{Z}_i$ and by M_i a mass of survivals in country i in equilibrium such that

$$M_i = [1 - \Omega(\phi^*_{br,i})]M_{e,i} \tag{19}$$

The surviving firms are allocated across brown and green market segments according to the productivity distribution and the equilibrium cutoff productivities such that

$$M_{br,i} = \frac{\Omega(\phi^*_{gr,i}) - \Omega(\phi^*_{br,i})}{1 - \Omega(\phi^*_{br,i})} M_i \tag{20}$$

$$M_{gr,i} = \frac{1 - \Omega(\phi^*_{gr,i})}{1 - \Omega(\phi^*_{br,i})} M_i \tag{21}$$

Goods market clearing. Firms profit maximisation requires (4) and (5) for each firm to hold assuring the goods market clearing condition (22) to be satisfied.

$$M_{br,i}\overline{r}_{br,i} + M_{gr,i}\overline{r}_{gr,i} = M_{br,i}\overline{d}_{br,i} + M_{gr,i}\overline{d}_{gr,i}, \quad i = H, F, \tag{22}$$

where $\overline{r}_{br,i}$, $\overline{r}_{gr,i}$, $\overline{d}_{br,i}$, and $\overline{d}_{gr,i}$ represent average revenues and demand of brown and green goods respectively (see Appendix 7.1).

Labor market clearing. Labor demand emanates from the service sector, $L_{\mathcal{S}i} = \mathcal{S}_i$, from the government sector, $L_{\mathcal{G}i} = (1 - \mu)TL_i$, and from the manufacturing sector, $L_{\mathcal{Z}i} = L_{br,i} + L_{gr,i} + L_{e,i}$, where $L_{br,i}$, $L_{gr,i}$, $L_{e,i}$ denote the labor required by brown, green and entering firms of sector $\mathcal{Z}$ respectively.

The labor market clearing condition is

$$L_i = L_{\mathcal{S}i} + L_{\mathcal{G}i} + L_{\mathcal{Z}i} \tag{23}$$

Equilibrium. After replacing average prices, price indices, and a mass of entering firms into (11), (12), and (18), these equations constitute a system of six independent equations that determines the six endogenous variables of the model $\left\{\phi^*_{br,i}, \phi^*_{gr,i}, M^*_i\right\}, i = H, F$. To close the general equilibrium we require the labor market clearing condition (23) to hold which will determine the size of the outside sector $L_{\mathcal{S}i}$. Note that the equilibrium is based on the assumption that an outside sector $\mathcal{S}$ is big enough to absorb all possible changes in demand for labor that requires $L_{\mathcal{S}i} > \mu(L_H + L_F), i = H, F$.

5 Policy Scenarios

The designed framework allows the study of the outcomes of different types of environmental policy in autarky and upon opening to international trade. In autarky we compare the efficiency of carrot and stick policies. In open economy three scenarios are to be investigated depending on the choice of the policy type across countries: two analogous when both implement taxation or green public procurement, and one dissimilar when countries opt for different programmes. When countries introduce analogous strategies, we can also study the impact of policy stringency heterogeneity across countries.

We investigate the comparative statics of all the scenarios and illustrate the results with numerical simulations. The numerical analysis is based on the following set of parameters: emissions intensity $\alpha = 0.5$ and $\alpha = 1$, elasticity of substitution between varieties $\sigma = 4$, productivity is Pareto-distributed with shape $k = 4.25$ and scale $\phi_0 = 1$, fixed costs: of entry $F_e = 1$, brown technology $F_b = F_e$, green technology $F_g = 1.25F_b$; increase in variable costs and decrease in emissions due to cleaner technology introduction $c = 1.05$ and $\delta = 0.9$ respectively; emissions efficiency $\alpha = 1$; size of the economy $L = 1000$; income tax $T = 0.06$, Cobb-Douglas expenditure share $\mu = 0.3$.

5.1 Autarky

In autarky two green policy scenarios are considered - stick policy (environmental taxation) and carrot policy (GPP).

The efficiency of stick policy depends on the green technology parameters. Within the current framework firms introduce an eco-friendly programme if the latter allows selling goods at lower prices in comparison with brown programmes. A decline in prices is related to higher emissions efficiency yielding lower tax payments.

No firms choose green technology if $\forall \phi, \left(\frac{1}{\phi} + \frac{t}{\phi^\alpha}\right) < \left(\frac{c}{\phi} + \frac{t\delta}{\phi^\alpha}\right)$. That implies $\phi^{1-\alpha} \leq \frac{(c-1)}{t(1-\delta)}$. If the latter holds, an additional policy instrument such as subsidy is required to reach the environmental goals. Thus, for low tax levels firms tend to remain brown. Only when the tax ratio reaches the threshold that allows producers to reduce the variable costs by introducing environmentally friendly technologies, the green sector is developed.

Comparing the two policies, we observe analogous changes in welfare, emissions, and green productivity cutoffs under both scenarios while the dynamics of a brown productivity cutoff remains the same under the carrot scenario but depends on the emissions elasticity under the stick scenario (see Appendix 7.2 for the comparative statics analysis and Figures 3 and 4 for the numerical simulations).

Under the environmental taxation scenario, emissions efficiency α determines the price structure: if $\alpha \in [0, 1)$, taxes dominate production costs in the price structure, the opposite otherwise. Accordingly, if there are highly polluting industries $\alpha \in (0, 1)$ the redistribution of environmental tax revenues to consumers significantly affects the demand. Therefore, more stringent policy allows room for new less productive firms to enter the market. If the industry is relatively less polluting $\alpha \in [1, \sigma]$, higher taxation strengthens the competition forcing the least productive firms to leave the market. Meanwhile, the dynamics of green cutoff productivity is not related to emission efficiency: in any case it is decreasing as a result of firms' willingness to lower the impact of taxation by introducing more environmentally-friendly technology. Tougher taxation naturally leads to a decrease in welfare and emissions.

More benevolent carrot policy also toughens the competition enlarging the green segment and leading to the exit of less efficient brown firms. The effect on welfare and emissions is identical to the stick scenario.

To compare the efficiency of stick and carrot regulation we introduce *elasticity of aggregate emissions with respect to aggregate welfare* $\frac{\Delta \mathcal{E}/\mathcal{E}}{\Delta V/V}$, where $\mathcal{E}$ represents aggregate emissions and V - indirect aggregate utility. Figure 5 shows that for all considered levels of policy instruments the elasticity is positive: the negative environmental impact can be reduced at the expenses of welfare. Meanwhile, despite the fact that stick policy generates higher

Figure 3: *Effects of environmental policy in autarky* ($\alpha = 0.5$)

(a) Stick (b) Carrot

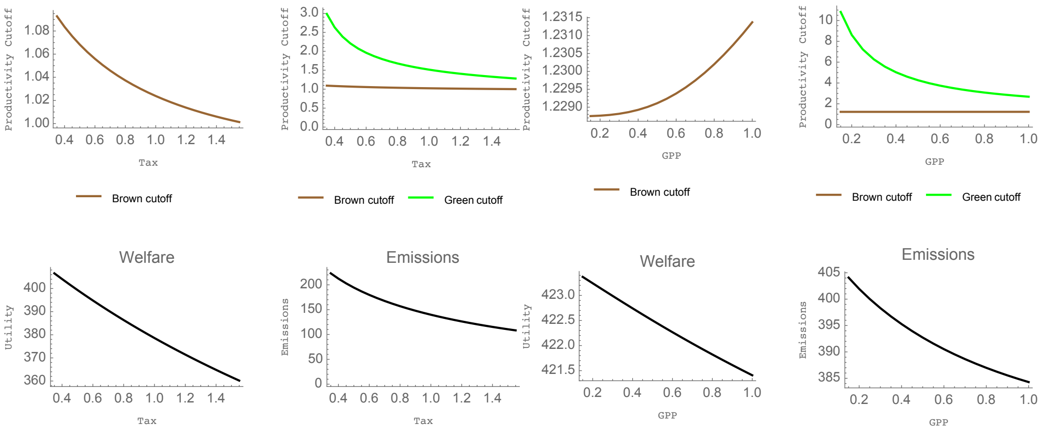


Figure 4: *Effects of environmental policy in autarky* ($\alpha = 1$)

(a) Stick (b) Carrot

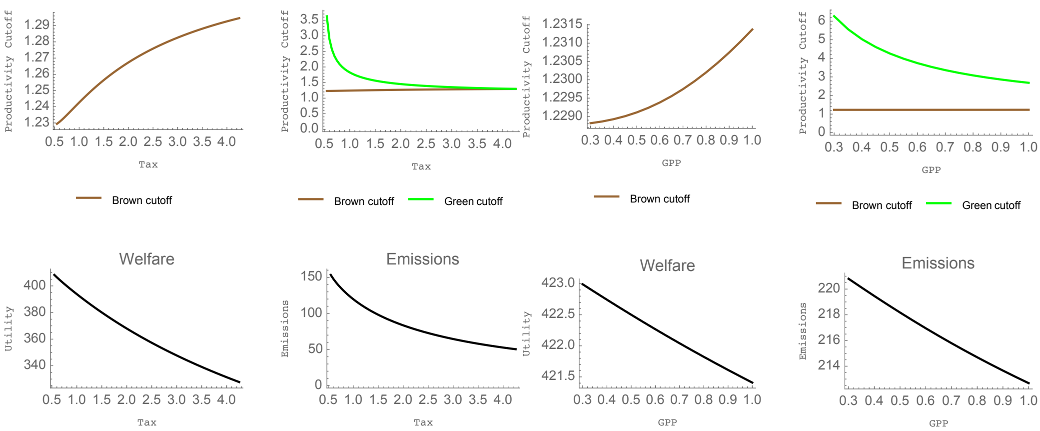
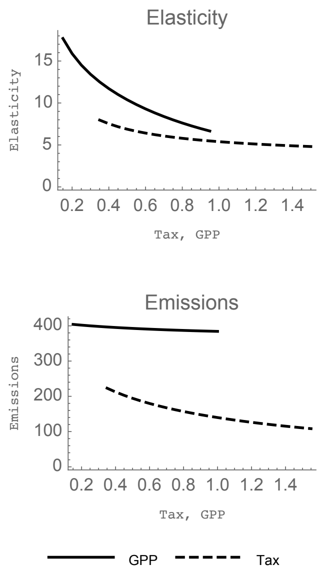
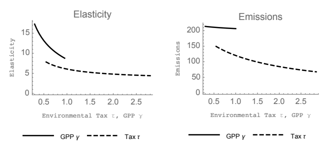


Figure 5: *Elasticity of aggregate emissions with respect to aggregate welfare in autarky*

(a) $\alpha = 0.5$



(b) $\alpha = 1$



environmental effects in absolute dimensions, the carrot approach is more pollution-welfare efficient.

5.2 Trade

Upon trade integration we consider three cases - “stick-stick”, “carrot-carrot”, and “stick-carrot” - according to the implemented environmental policy (see Appendix 7.3 for comparative statics analysis and Table 1 for the results). In the first two scenarios we study the model under two assumptions when countries introduce the same type of policy. In each case we compare the consequences of trade integration when green policy is similar ($t_0 = t_F = t_H = 1$, $\gamma_0 = \gamma_F = \gamma_H = 0.5$) or different ($t_H = 0.75$, $t_F = 1.25$; $\gamma_H = 0.25$, $\gamma_F = 0.75$) in its stringency/benevolence. The third scenario illustrates the case when one country introduces environmental taxation ($t_H = 1$, $\gamma_H = 0$) while the trading partner opts for a GPP programme ($t_F = 0$, $\gamma_F = 0.5$).

Table 1: *Effects of green policy with exposure to trade*

Scenario	Brown cutoff	Green cutoff	Welfare	Emissions
Tax-Tax				
identical	0	0	⇑	0
higher	0	0	⇓	⇓
lower	0	0	⇑	⇑
GPP-GPP				
identical	⇓	⇑	⇑	⇓
higher	⇓	⇑	⇑	⇑
lower	⇓	⇑	⇓	⇓
Tax-GPP				
tax	0	0	⇓	⇓
GPP	⇓	⇑	⇑	⇑

Note: Under the highlighted scenarios countries benefit from trade integration.

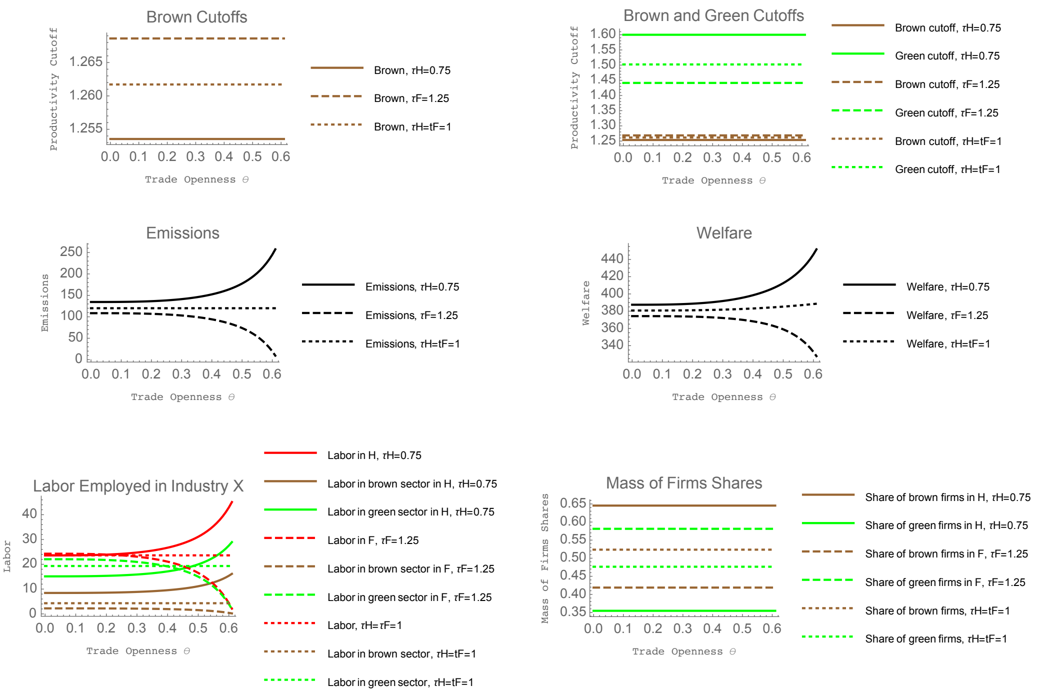
5.2.1 "Stick-stick" scenario

First, let's consider the case when both trading countries introduce environmental taxation. If the level of taxation is identical across countries ($t_0 = 1$), the only change induced by increasing openness to trade is welfare growth (Figure 6). This result is well-known in the literature as "love-of-variety" effect: consumers benefit from a wider range of products due to trade integration. That corresponds to a "win-win" situation when both countries benefit from exposure to trade.

Second, let's assume that country H is less eco-concerned in comparison with country F such that $t_H = 0.75 < t_F = 1.25$. Then emission intensity determines the initial composition of brown cutoff productivities: if $\alpha \in [1, \sigma)$, $\phi^*_{br,F} > \phi^*_{br,H}$, the opposite otherwise. Thus, as under autarky, low emissions intensity combined with a tax transfer to consumers opens room for less productive firms to enter the market. Meanwhile, the order of green cutoffs remains the same $\phi^*_{gr,F} < \phi^*_{gr,H}$.

Due to the absence of fixed exporting costs we observe a collateral effect on cutoff productivities with increasing trade integration. In contrast to

Figure 6: *Trade, "stick - stick" scenario*, $\alpha = 1$, $t_0 = 1$, $t_H = 0.75$, $t_F = 1.25$



the case with identical countries, the impact on emissions and welfare is conditional to the green policy stringency. Country H with a relatively less severe regulation experiences welfare and emissions growth. Both effects stem from a relatively higher level of domestic producers' competitiveness as a result of lower taxation. Country F who introduces more severe regulation faces the opposite situation: consumers lose due to higher distortion based on taxes but at the same time the economy gains from lower emissions. Accordingly, lower taxation fosters incomplete specialisation of country H on manufacturing products leading to emissions growth, while country F experiences emissions decline as a result of stricter taxation. Therefore, the overall effect of trade integration on both countries is conditional to the relative magnitude and perception of environmental degradation and welfare growth.

5.2.2 "Carrot-carrot" scenario

In the second case we consider GPP programmes to be the only type of green policy. In comparison with a "stick-stick" scenario, exposure to trade leads to changes in all parameters of interest, particularly, cutoff productivities, emissions, and welfare (Figure 7).

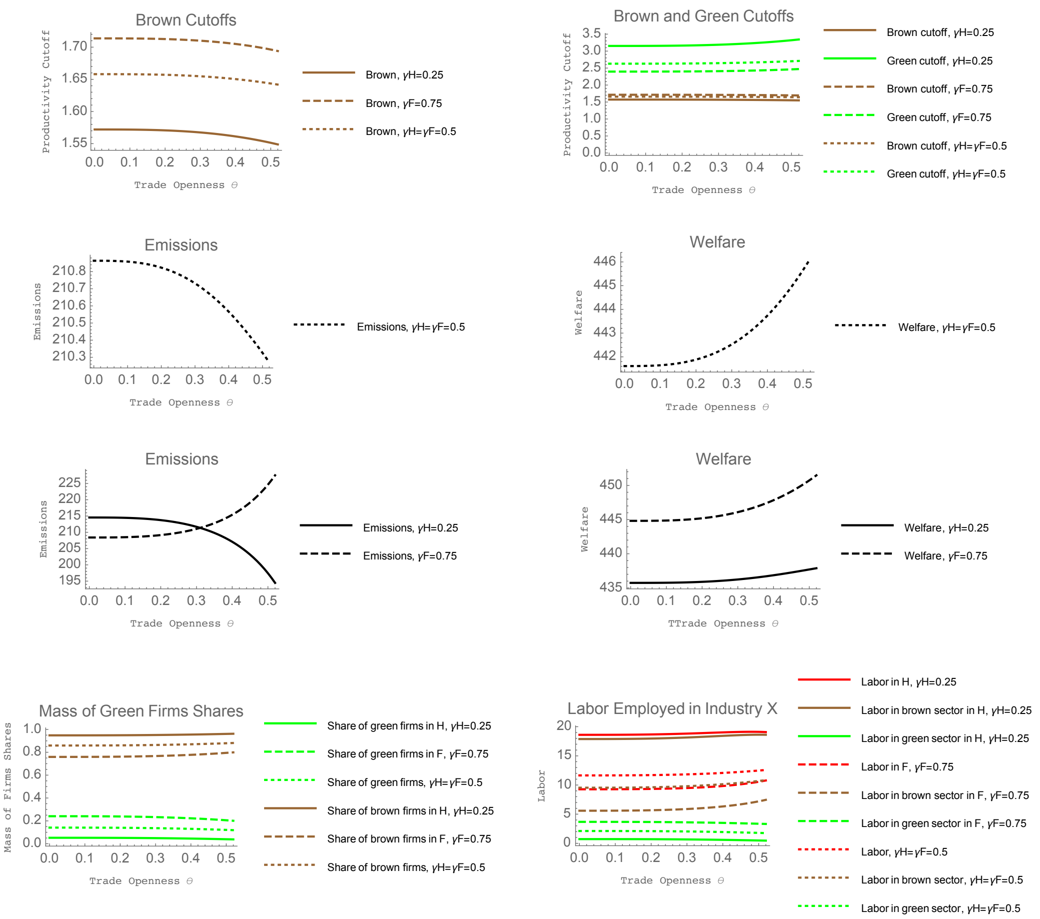
In both cases, when GPP policies are identical or different, collateral effects are the same across countries. Trade toughens competition in the green segment that becomes more productive which, in its turn, pins down the price index increasing eco-biased demand. At the same time the least productive green firms who are forced to discontinue environmentally-friendly production disengage the labor required by cleaner technologies. That opens the market for less efficient newcomers who join the brown segment. As a result, the green cutoff productivity increases and the brown cutoff productivity declines.

Meanwhile, the welfare and emission effects depend on the cross-country GPP policy differences. Exposure to trade between identical countries ($\gamma_0 = 0.5$) leads to a welfare increase. This is in line with the well-known result of trade integration and emissions decrease that is at odds with some findings in the literature arguing that trade integration leads to emissions growth[24]. Thus, the model delivers a "win-win" situation when both countries observe lower emissions and higher welfare.

When countries introduce different GPP programmes, the outcomes are ambiguous. A higher share of government spendings to green goods increases the competition and, accordingly, welfare as a result of the higher productivity of producing firms. Meanwhile, the attractiveness of the market also incurs higher emissions. The effects for the country with relatively lower spendings on GPP are the opposite. As a result, the outcomes for both countries are inconclusive and depend on the relative magnitude and perception of pollution and welfare as in a "stick-stick" scenario with heterogeneous green policies.

[24] See Cherniwchan et al. (2017) for a recent overview of the problem.

Figure 7: *Trade, "carrot-carrot" scenario,* $\alpha = 1$, $\gamma_0 = 0.5$, $\gamma_H = 0.25$, $\gamma_F = 0.75$



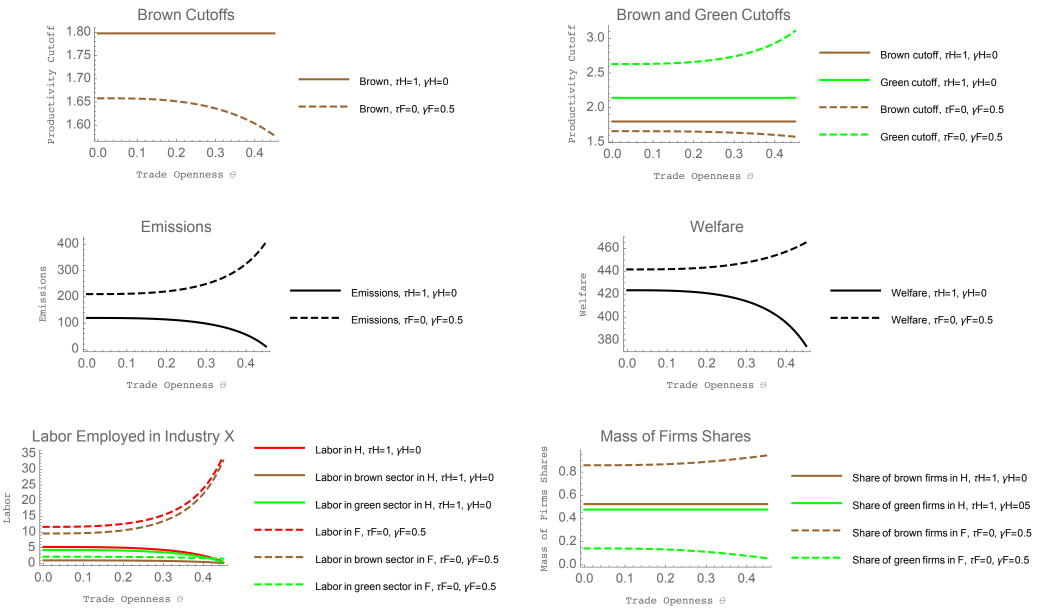
5.2.3 "Stick-carrot" scenario

In the third scenario we consider when countries are heterogeneous in the type of implemented green public policy: country H introduces environmental taxation ($t_H = 0.75$) but no GPP ($\gamma_H = 0$) while country F opts for green public purchasing ($\gamma_F = 0.5$) but zero carbon tax ($t_F = 0$).

As in a "stick-stick" scenario, emission intensity determines the ratio of brown cutoff productivities across countries: $\alpha \in [0, 1)$ dampens the cutoff in country H who opts for an environmental tax policy.

The trade integration effects in the "stick-carrot" scenario is analogous

Figure 8: *Trade, "stick-carrot" scenario,* $\alpha = 1$, $t_H = 0.75$, $t_F = 0$, $\gamma_H = 0$, $\gamma_F = 0.5$



to the "carrot-carrot" scenario with heterogeneous green policies. The only difference stems from the stability of productivity cutoffs in country H for any level of trade costs (Figure 8).

6 Discussion and Conclusion

Our analysis aims to better understand the main and collateral effects of two different green policy instruments, environmental taxation and green public procurement. The former represents a traditional mandatory approach that directly impacts ecological damage while the latter implies voluntary decisions acting indirectly through the government demand. At the same time, both instruments incentivise producers to introduce more environmentally friendly technologies. The object of the research is of current importance due to the topicality of environmental problems and the ongoing intensive investigation into the most efficient and least distortive regulatory instruments.

Moreover, our focus on GPP reflects the worldwide intention of policy makers to promote green purchasing as a tool with strong potential to address a wide range of environmental problems. This attitude is at odds with the theoretical literature where the findings concerning GPP remain unconvinced and vigilant of highly likely negative side effects.

Our research contributes to the existing studies in several dimensions, however, we do not assert this work as a comprehensive model covering all key consequences of the both instruments of interest. On the contrary, we consider several limitations to the analysis to focus on the pure effect of government policy without supportive actions of other economic agents. Thus, the assumptions of the model imply environmental indifference of consumers, innovation-incentive nature of the mandatory approach, and absence of fixed exporting costs that allows all firms to benefit from trade integration.

The model highlights a set of new pros and cons concerning both the implementation of regulatory instruments in autarky and upon opening to trade. The analysis partly challenges the scepticism about GPP showing the relative efficiency of the instrument in comparison with taxation under particular assumptions.

Our results contribute to a wide discussion on the environmental effects of trade integration which can be deconstructed into four partial effects: a *scale* effect related to the economic activity increase; a *technique* effect related to firm-level emissions intensity changes (for example, as a result of changes in environmental regulation); a *composition* effect related to a factor allocation across sectors; and a *reallocation* effect related to the exit of less productive and more pollution intensive firms[25]. In our approach we mainly focus on the scale and technique effects. The latter also covers reallocation as a result of productivity changes under GPP regulation. We show that both effects can correspond to beneficial outcomes - conditionally, depending on the degree of trade integration and the composition of policy instruments.

Thus, we show a higher relative efficiency of GPP in comparison with tax-

[25] The first three effects were proposed by Grossman and Krueger (1993) and then theoretically shaped by Copeland and Scott Taylor (2004), and the fourth one was introduced by Kreickemeier and Richter (2014).

ation under autarky. In the open economy setting we illustrate the ambiguity of welfare and environmental outcomes across countries upon trade integration. If trading partners introduce analogous public policies, they both face a simultaneous decrease or increase of emissions and welfare, conditional to the green public policy cross-country differences, which makes the overall effect inconclusive. If trading partners opt for different public policies, GPP strategy delivers potentially worse ecological outcomes which creates higher emissions but higher welfare in comparison with taxation that leads to welfare and emissions decline. The only possible "win-win" situations are when both trading partners choose identical taxation or GPP programmes that leads to emissions decline and welfare growth. Therefore, our findings contribute to the discussion of green public policy design and the cross-country harmonisation of regulatory instruments in the open economy. The harmonised regulation, both GPP and taxation, can potentially benefit both parties while in heterogeneous policy settings the outcomes are inconclusive.

To the best of our knowledge, this is the first attempt to address the issue of GPP in comparison with environmental taxation in the general equilibrium framework with several types of heterogeneity. However, our model overlooks a set of possibly relevant effects. The most significant elements missing from our model are the eco-blindness of consumers and producers, the absence of obstacles while opening to international trade, and the similarities across countries. Although these assumptions allow us to isolate the effect of government policy, by relaxing them one could obtain results that would overrule the outcomes of this paper. However, the current research sheds more light on the consequences of green public procurement, adding a set of arguments to the topical discussion on the optimal design of environmental regulation.

References

Albrizio, S., E. Botta, T. Koźluk, and V. Zipperer (2014). Do environmental policies matter for productivity growth?

Arvidsson, A. and J. Stage (2012). Technology-neutral green procurement in practice – an example from swedish waste management. *Waste Management and Research 30*(5), 519–523.

Batrakova, S. and R. B. Davies (2012). Is there an environmental benefit to being an exporter? evidence from firm-level data. *Review of World Economics 148*, 449–474.

Brülhart, M. and F. Trionfetti (2004). Public expenditure, international specialisation, and agglomeration. *European Economic Review 48*, 851–881.

Cerutti, A. K., S. Contu, F. Ardente, D. Donno, and G. L. Beccaro (2016). Carbon footprint in green public procurement: Policy evaluation from a case study in the food sector. *Food Policy 58*, 82–93.

Cherniwchan, J., B. R. Copeland, and M. Scott Taylor (2017). Trade and the environment: New methods, measurements, and results. *Annual Review of Economics 9*.

Cole, M. A., R. J. Elliott, and S. Wu (2008). Industrial activity and the environment in china: An industry-level analysis. *China Economic Review 19*, 393–408.

Copeland, B. R. and M. Scott Taylor (2004, March). Trade, growth, and the environment. *Journal of Economic Literature 42*(1), 7–71.

Cui, J., H. Lapan, and G. Moschini (2012, October). Are exporters more environmentally friendly than non-exporters? theory and evidence.

EC (2008). Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions on the sustainable consumption and production and sustainable industrial policy action plan. Technical Report COM 397/3, European Comission.

EC (2012). Green public procurement. a collection of good practices. Technical report, European Commission.

EC (2016). Buying green! a handbook on green procurement. 3rd edition. Technical report, European Commission.

EU (2016). Taxation trends in the european union. Technical report, Taxation and Customs Union.

Fet, A. M., O. Michelsen, and L. de Boer (2011). Green public procurement in practice - the case of norway. *Society and Economy 33*, 183–198.

Forslid, R., T. Okubo, and K. H. Ulltveit-Moe (2015). Why are firms that export cleaner? international trade, abatement and environmental emissions.

Geng, Y. and B. Doberstein (2008). Greening government procurement in developing countries: Building capacity in china. *Journal of Environmental Managementn 88*, 932–938.

Grossman, G. M. and A. B. Krueger (1993). *erican Free Trade Agreement," In P. M. Garber (ed.),*, Chapter Environmental Impacts of a North American Free Trade Agreement, pp. 13–56. Cambride, MA: The MIT Press.

Ho, L. W., N. M. Dickinson, and G. Y. Chan (2010). Green procurement in the asian public sector and the hong kong private sector. *National Resources Forum*, 24–38.

Igarashi, M., L. de Boer, and O. Michelsen (2015). Investigating the anatomy of supplier selection in green public procurement. *Journal of Cleaner Production 108*, 442–450.

Kreickemeier, U. and P. M. Richter (2014). Trade and the environment: The role of firm heterogeneity. *Review of International Economics 22*(2), 209–225.

Lundberg, S. and P.-O. Marklund (2011). The pivotal nature of award methods in green public procurement. *Environmental Economics 2*(3), 64–73.

Lundberg, S. and P.-O. Marklund (2013). Green public procurement as an environmental policy instrument: cost effectiveness. *Environmental Economics 4*(4), 75–83.

Lundberg, S., P.-O. Marklund, and E. Strömback (2015). Is environmental policy by public procurement effective? *Public Finance Review*, 1–22.

Lundberg, S., P.-O. Marklund, E. Strömback, and D. Sundström (2015). Using public procurement to implement environmental policy: an empirical analysis. *Environmental Economics Policy Studies 17*, 487–520.

Marron, D. B. (1997, May). Buying green: Government procurement as an instrument of environmental policy. *Public Finance Review 25*(3), 285–305.

Marron, D. B. (2003). Green public purchasing as an environmental policy instrument. *OECD Journal on Budgeting 3*(4), 71–105.

McEldowney, J. and D. Salter (2015). Environmental taxation in the uk: the climate change levy and policy making. *Denning Law Journal 28*, 37–65.

Michelsen, O. and L. de Boer (2009). Green procurement in norway: a survey of practices at the municipal and county level. *Journal of Environmental Management 91*, 160–167.

Milne, J. E. (2011). Environmental taxation in the united states: the long view. *Lewis and Clark Law Review 15*(2), 417–449.

Mosgaard, M., H. Riisgaard, and R. D. Huulgaard (2013). Greening non-product-related procurement e when policy meets reality. *Journal of Cleaner Production 39*, 137–145.

Ochoa, A., V. Führ, and D. Günter (2003, November). *Buying into the Environment: Experiences, Opportunities and Potential for Eco-procurement*, Chapter Green Purchasing in Practice. Experiences and New Approaches from the Pioneer Countries., pp. 20–. Number 2. Greenleaf Publishing.

OECD (2011). Government at a glance. Technical report, OECD Publishing.

OECD (2015). Going green: Best practices for sustainable procurement. Technical report, OECD.

Oosterhuis, F., F. Rubik, and G. Scholl (1996). *Product Policy in Europe: New Environmental Perspectives*. Kluwer Academic Publishers.

Parikka-Alhola, K. (2008). Promoting environmentally sound furniture by green public procurement. *Ecological Economics 68*, 472–485.

PricewaterhouseCoopers, S. and Ecofys (2009). Collection of statistical information on green public procurement in the eu. Technical report, PricewaterhouseCoopers.

Qiao, Y. and C. Wang (2011). Issues and challenges in implementing china's green public procurement program. *Journal of Environmental Protection 2*, 1034–1045.

Renda, A., J. Pelkmans, C. Egenhofer, L. Schrefler, G. Luchetta, C. Selçuki, J. Ballesteros, and A.-C. Zirnhelt (2012). The uptake of green public procurement in the eu27. Technical report, European Union.

Rodrigue, J. and O. Soumonni (2014). Deforestation, foreign demand and export dynamics in indonesia. *Journal of International Economics 93*, 316–338.

Scott Holladay, J. (2016). Exporters and the environment. *Canadian Journal of Economics 49*(1), 147–172.

Simcoe, T. and M. W. Toffel (2014). Government green procurement spillovers: Evidence from municipal building policies in california. *Journal of Environmental Economics and Management 68*, 411–434.

Testa, F., P. Grappio, N. M. Gusmerotti, F. Iraldo, and M. Frey (2016). Examining green public procurement using content analysis: existing difficulties for procurers and useful recommendations. *Environment, Development and Sustainability 18*(1), 197–219.

Testa, F., F. Iraldo, M. Frey, and T. Daddi (2012). What factors influence the uptake of gpp (green public procurement) practices? new evidence from an italian survey. *Ecological Economics 82*, 88–96.

Trionfetti, F. (2001). Public procurement, market integration, and income inequalities. *Review of International Economics 9*(1), 29–41.

Tsai, W.-T. (2017). Green public procurement and green-mark products strategies for mitigating greenhouse gas emissions—experience from taiwan. *Mitigation and Adaptation Strategies for Global Change 22*(729).

Valkó, L. and A. Kiss (2005). Eco-lablels in hungarian public procurement. *Periodica Polytechnica Social and Management Sciences 13*(2), 107–120.

Zhu, Q., Y. Geng, and J. Sarkis (2013). Motivating green public procurement in china: An individual level perspective. *Journal of Environmental Management 126*, 85–95.

7 Appendix

7.1 Aggregation

Average brown and green prices

$$\widetilde{p}_{br} = \left[\frac{1}{\Omega(\phi^*_{gr}) - \Omega(\phi^*_{br})} \int_{\phi^*_{br}}^{\phi^*_{gr}} p_{br}^{1-\sigma}(\phi) d\Omega(\phi) \right]^{1/(1-\sigma)} \tag{24}$$

$$\widetilde{p}_{gr} = \left[\frac{1}{1 - \Omega(\phi^*_{gr})} \int_{\phi^*_{br}}^{\infty} p_{gr}^{1-\sigma}(\phi) d\Omega(\phi) \right]^{1/(1-\sigma)} \tag{25}$$

Accordingly, price indexes for brown and green sectors, and for the whole market

$$P_{i,br} = \left[M_{i,br} \widetilde{p}_{br}^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{26}$$

$$P_{i,gr} = \left[M_{i,gr} \widetilde{p}_{gr}^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{27}$$

$$P_{i} = \left[P_{i,br}^{1-\sigma} + P_{i,gr}^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{28}$$

Average demand for brown and green varieties respectively

$$\overline{d}_{br,i} = \widetilde{p}_{br}^{1-\sigma} \left(\mathcal{B}_i^g + \mathcal{B}_i^h + \tau^{\sigma-1} (\mathcal{B}_j^g + \mathcal{B}_j^h) \right) \tag{29}$$

$$\overline{d}_{gr,i} = \widetilde{p}_{gr}^{1-\sigma} \left(\mathcal{B}_i^g + \mathcal{B}_{gr,i}^g + \mathcal{B}_i^h + \tau^{\sigma-1} (\mathcal{B}_j^g + \mathcal{B}_{gr,j}^g + \mathcal{B}_j^h \right) \tag{30}$$

Average revenues of brown and green firms

$$\overline{r}_{br} = \frac{1}{\Omega(\phi^*_{gr}) - \Omega(\phi^*_{br})} \int_{\phi^*_{br}}^{\phi^*_{gr}} r_{br}(\phi) d\Omega(\phi) \tag{31}$$

$$\overline{r}_{gr} = \frac{1}{1 - \Omega(\phi^*_{gr})} \int_{\phi^*_{br}}^{\infty} r_{gr}(\phi) d\Omega(\phi) \tag{32}$$

Average brown and green profits

$$\overline{\pi}_{br} = \frac{1}{\Omega(\phi^*_{gr}) - \Omega(\phi^*_{br})} \int_{\phi^*_{br}}^{\phi^*_{gr}} \pi_{br}(\phi) d\Omega(\phi) \tag{33}$$

$$\overline{\pi}_{gr} = \frac{1}{1 - \Omega(\phi^*_{gr})} \int_{\phi^*_{br}}^{\infty} \pi_{gr}(\phi) d\Omega(\phi) \tag{34}$$

Average labor demand of brown and green firms

$$\bar{l}_{br} = \frac{1}{\Omega(\phi_{gr}^*) - \Omega(\phi_{br}^*)} \int_{\phi_{br}^*}^{\phi_{gr}^*} l_b(\phi) d\Omega(\phi) \tag{35}$$

$$\bar{l}_{gr} = \frac{1}{1 - \Omega(\phi_{gr}^*)} \int_{\phi_{br}^*}^{\infty} l_{gr}(\phi) d\Omega(\phi) \tag{36}$$

Labor in manufacturing sector

$$L_{Mi} = M_{br}\left(\bar{l}_{br} + F_{br}\right) + M_{gr}\left(\bar{l}_{gr} + F_{gr}\right) + M_e F_e \tag{37}$$

Aggregate emissions

$$\mathcal{E}_i = \frac{M_{br}}{\Omega(\phi_{gr}^*) - \Omega(\phi_{br}^*)} \int_{\phi_{br}^*}^{\phi_{gr}^*} \frac{q_{br}(\phi)}{\phi^\alpha} d\Omega(\phi) + \frac{\delta M_{gr}}{1 - \Omega(\phi_{gr}^*)} \int_{\phi_{br}^*}^{\infty} \frac{q_{gr}(\phi)}{\phi^\alpha} d\Omega(\phi) \tag{38}$$

7.2 Comparative Statics: Autarky

For the autarky case we drop the country index.

7.2.1 Taxation

Plugging zero profit condition (11) into no-arbitrage (12) and free entry (18) conditions, we obtain the system of two equations (39) and (40) with two unknowns, ϕ_{br}^* and ϕ_{gr}^* that allows for comparative statics analysis of cutoffs productivities:

$$p_{br}(\phi_{br}^*)^{\sigma-1}\left\{p_{gr}(\phi_{gr}^*)^{1-\sigma} - p_{br}(\phi_{gr}^*)^{1-\sigma}\right\} = \frac{F_{gr} - F_{br}}{F_{br}} \tag{39}$$

$$F_{br} p_{br}(\phi_{br}^*)^{\sigma-1}\left\{\int_{\phi_{br}^*}^{\phi_{gr}^*} p_{br}(\phi)^{1-\sigma} d\Omega(\phi) + \int_{\phi_{gr}^*}^{\infty} p_{gr}(\phi)^{1-\sigma} d\Omega(\phi)\right\} - F_{br}[\Omega(\phi_{gr}^*) - \Omega(\phi_{br}^*)] - F_{gr}[1 - \Omega(\phi_{gr}^*)] = F_e \tag{40}$$

Accordingly,

$$\left.\frac{d\phi_{br}^*}{dt}\right|_{t=0} = \phi_{br}^* \frac{\int_{\phi_{br}^*}^{\infty} \phi^{\sigma-1}[(\phi_{br}^*)^{1-\alpha} - \phi^{1-\alpha}] d\Omega(\phi)}{\int_{\phi_{br}^*}^{\infty} \phi^{\sigma-1} d\Omega(\phi)} \tag{41}$$

$$\left.\frac{d\phi_{gr}^*}{dt}\right|_{t=0} = \phi_{gr}^* \frac{\int_{\phi_{br}^*}^{\infty} \phi^{\sigma-1}\left[\frac{\delta c^{-\sigma}-1}{c^{1-\sigma}-1}(\phi_{gr}^*)^{1-\alpha} - \phi^{1-\alpha}\right] d\Omega(\phi)}{\int_{\phi_{br}^*}^{\infty} \phi^{\sigma-1} d\Omega(\phi)} \tag{42}$$

Aggregate emissions

$$\mathcal{E} = \frac{\mu L \left[\int_{\phi^*_{br}}^{\phi^*_{gr}} p_{br}(\phi)^{-\sigma}\phi^{-\alpha}d\Omega(\phi) + \delta\int_{\phi^*_{gr}}^{\infty} p_{gr}(\phi)^{-\sigma}\phi^{-\alpha}d\Omega(\phi)\right]}{\int_{\phi^*_{br}}^{\phi^*_{gr}} p_{br}(\phi)^{-\sigma}(p_{br}(\phi) - t\phi^{-\alpha})d\Omega(\phi) + \mu t\int_{\phi^*_{gr}}^{\infty} p_{gr}(\phi)^{-\sigma}(p_{gr}(\phi) - \delta t\phi^{-\alpha})d\Omega(\phi)} \tag{43}$$

Indirect utility is represented as $V = I^h P^{-\mu}$ where

$$P^{\sigma-1} = \frac{\sigma F_{br}}{\mu L}[p_{br}(\phi^*_{br})^{\sigma-1}] \frac{\int_{\phi^*_{br}}^{\phi^*_{gr}} p_{br}(\phi)^{-\sigma}(p_{br}(\phi) - t\phi^{-\alpha})d\Omega(\phi) + \mu t\int_{\phi^*_{gr}}^{\infty} p_{gr}(\phi)^{-\sigma}(p_{gr}(\phi) - \delta t\phi^{-\alpha})d\Omega(\phi)}{\int_{\phi^*_{br}}^{\phi^*_{gr}} p_{br}(\phi)^{1-\sigma}d\Omega(\phi) + \int_{\phi^*_{gr}}^{\infty} p_{gr}(\phi)^{1-\sigma}d\Omega(\phi)} \tag{44}$$

$$I^h = (1-T)L + t\mathcal{E} \tag{45}$$

Then

$$\left.\frac{d\phi^*_{br}}{dt}\right|_{t=0} < 0, \quad 0 \le \alpha < 1 \tag{46}$$

$$\left.\frac{d\phi^*_{br}}{dt}\right|_{t=0} > 0, \quad \alpha \ge 1 \tag{47}$$

$$\left.\frac{d\phi^*_{gr}}{dt}\right|_{t=0} < 0 \tag{48}$$

$$\left.\frac{dV}{dt}\right|_{t=0} < 0, \qquad \left.\frac{d\mathcal{E}}{dt}\right|_{t=0} < 0 \tag{49}$$

7.2.2 Green public procurement

Zero profit condition (11) and the definition of a price index allow to obtain mass of firms M as a function of cutoff productivities such that

$$M = \frac{[1-\Omega(\phi^*_{br})]\mu L(1-\gamma T)(\phi^*_{br})^{\sigma-1}}{\sigma F_{br}\left\{\int_{\phi^*_{br}}^{\phi^*_{gr}} \phi^{\sigma-1}d\Omega(\phi) + c^{1-\sigma}\int_{\phi^*_{gr}}^{\infty} \phi^{\sigma-1}d\Omega(\phi)\right\}} \tag{50}$$

Then

$$P^{1-\sigma} = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \frac{\mu L(1-\gamma T)(\phi^*_{br})^{\sigma-1}}{\sigma F_{br}} \tag{51}$$

$$P_{gr}^{1-\sigma} = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \frac{\mu L(1-\gamma T)(\phi_{br}^*)^{\sigma-1}}{\sigma F_{br}\left\{c^{\sigma-1}\frac{\int_{\phi_{br}^*}^{\phi_{gr}^*}\phi^{\sigma-1}d\Omega(\phi)}{\int_{\phi_{gr}^*}^{\infty}\phi^{\sigma-1}d\Omega(\phi)}+1\right\}} \tag{52}$$

Accordingly,

$$P^{1-\sigma} = \left\{c^{\sigma-1}\frac{\int_{\phi_{br}^*}^{\phi_{gr}^*}\phi^{\sigma-1}d\Omega(\phi)}{\int_{\phi_{gr}^*}^{\infty}\phi^{\sigma-1}d\Omega(\phi)}+1\right\}P_{gr}^{1-\sigma} \tag{53}$$

Plugging (51) and (52) into no-arbitrage (12) and free entry (18) conditions, one can obtain the system of two equations (54) and (55) with two unknowns, ϕ_{br}^* and ϕ_{gr}^* that allows for comparative statics analysis:

$$\frac{F_{gr}-F_{br}}{F_{br}}(\phi_{gr}^*)^{1-\sigma}(\phi_{br}^*)^{\sigma-1} = \left(\frac{\gamma T}{1-\gamma T}\right)\frac{\int_{\phi_{br}^*}^{\phi_{gr}^*}\phi^{\sigma-1}d\Omega(\phi)}{\int_{\phi_{gr}^*}^{\infty}\phi^{\sigma-1}d\Omega(\phi)}+\frac{c^{1-\sigma}}{1-\gamma T}-1 \tag{54}$$

$$\begin{aligned} &F_{br}(\phi_{br}^*)^{1-\sigma}\int_{\phi_{br}^*}^{\infty}\phi^{\sigma-1}d\Omega(\phi)+(F_{gr}-F_{br})(\phi_{gr}^*)^{1-\sigma}\int_{\phi_{gr}^*}^{\infty}\phi^{\sigma-1}d\Omega(\phi) \\ &-F_{br}[\Omega(\phi_{gr}^*)-\Omega(\phi_{br}^*)]-F_{gr}[1-\Omega(\phi_{gr}^*)]=F_e \end{aligned} \tag{55}$$

Then

$$\left.\frac{d\phi_{br}^*}{d\gamma}\right|_{\gamma=0} = \frac{T\phi_{br}^*}{(\sigma-1)} > 0 \tag{56}$$

$$\left.\frac{d\phi_{gr}^*}{d\gamma}\right|_{\gamma=0} = -\frac{F_{br}(\phi_{gr}^*)^{1-\sigma}\int_{\phi_{br}^*}^{\infty}\phi^{\sigma-1}d\Omega(\phi)}{(F_{gr}-F_{br})(\phi_{br}^*)^{1-\sigma}\int_{\phi_{gr}^*}^{\infty}\phi^{\sigma-1}d\Omega(\phi)}\left.\frac{d\phi_{br}^*}{d\gamma}\right|_{\gamma=0} < 0 \tag{57}$$

Indirect utility function

$$V = L(1-T)P^{-\mu} \tag{58}$$

Aggregate emissions

$$\mathcal{E} = \frac{(\sigma-1)\mu L(1-\gamma T)(\phi_{br}^*)^{\sigma-1}}{\sigma F_{br}\left\{\int_{\phi_{br}^*}^{\phi_{gr}^*}\phi^{\sigma-1}d\Omega(\phi) + c^{1-\sigma}\int_{\phi_{gr}^*}^{\infty}\phi^{\sigma-1}d\Omega(\phi)\right\}}$$

$$\left\{F_{br}(\phi_{br}^*)^{1-\sigma}\int_{\phi_{br}^*}^{\phi_{gr}^*}\phi^{\sigma-\alpha}d\Omega(\phi) + \delta c^{-1}F_{br}(\phi_{br}^*)^{1-\sigma}\int_{\phi_{gr}^*}^{\infty}\phi^{\sigma-\alpha}d\Omega(\phi)\right. \quad (59)$$

$$\left. + \delta c^{-1}(F_{gr}-F_{br})(\phi_{gr}^*)^{1-\sigma}\int_{\phi_{gr}^*}^{\infty}\phi^{\sigma-\alpha}d\Omega(\phi)\right\}$$

Accordingly,

$$\left.\frac{d\phi_{br}^*}{d\gamma}\right|_{\gamma=0} > 0, \qquad \left.\frac{d\phi_{gr}^*}{d\gamma}\right|_{\gamma=0} < 0 \quad (60)$$

$$\left.\frac{dV}{d\gamma}\right|_{\gamma=0} < 0, \qquad \left.\frac{d\mathcal{E}}{d\gamma}\right|_{\gamma=0} < 0 \quad (61)$$

7.3 Comparative Statics: Trade Integration

7.3.1 "Stick-Stick" Scenario

In the "stick-stick" scenario we follow the same procedure as under autarky to obtain the direction of cutoff productivities. Accordingly,

$$\frac{d\phi_{br,i}^*}{d\omega} = 0, \quad \frac{d\phi_{gr,i}^*}{d\omega} = 0, \quad i = H, F, \quad (62)$$

where $\omega \equiv \tau^{\sigma-1}$ is a measure of trade openness.

Aggregate emissions

$$\mathcal{E}_i = \mu L I_i \frac{J_j - \mu t_j I_j - \omega J_j(\phi_{br,i}^*)^{\sigma-1}(\phi_{gr,i}^*)^{1-\sigma}}{(1-\omega^2)J_iJ_j - \mu t_j I_j J_i - \mu t_i I_i J_j + \mu^2 t_i t_j I_i I_j}, \quad i = H, F, \quad (63)$$

where

$I_i \equiv \int_{\phi_{br,i}^*}^{\phi_{gr,i}^*} p_b(\phi)^{-\sigma}\phi^{-\alpha}d\Omega(\phi) + \delta\int_{\phi_{gr,i}^*}^{\infty} p_g(\phi)^{-\sigma}\phi^{-\alpha}d\Omega(\phi)$,

$J_i \equiv \int_{\phi_{br,i}^*}^{\phi_{gr,i}^*} p_b(\phi)^{1-\sigma}d\Omega(\phi) + \int_{\phi_{gr,i}^*}^{\infty} p_g(\phi)^{1-\sigma}d\Omega(\phi)$.

Indirect utility

$$V_i = ((1-T)L + t_i\mathcal{E}_i)P_i^{-\mu}, \quad (64)$$

where

$P_i^{1-\sigma} = \frac{\mu L}{\sigma F_{br}}\frac{J_i p_{br}(\phi_{br,i}^*)^{1-\sigma}[(1-\omega^2)J_j - \mu t_j I_j]\left(J_j - \mu t_j I_j - \omega J_j(\phi_{br,i}^*)^{\sigma-1}(\phi_{gr,i}^*)^{1-\sigma}\right)}{(J_j-\mu t_j I_j)((1-\omega^2)J_iJ_j - \mu t_j I_j J_i - \mu t_i I_i J_j + \mu^2 t_i t_j I_i I_j)} + \omega\frac{J_j p_{br}(\phi_{br,j}^*)^{1-\sigma}}{J_j - \mu t_j I_j}$.

Accordingly, if $t_H = t_F$,

$$\left.\frac{d\mathcal{E}_i}{d\omega}\right|_{\omega=0} = 0, \quad \left.\frac{dV_i}{d\omega}\right|_{\omega=0} > 0, \quad i = H, F \tag{65}$$

If $t_H < t_F$,

$$\left.\frac{d\mathcal{E}_H}{d\omega}\right|_{\omega=0} > 0, \quad \left.\frac{d\mathcal{E}_F}{d\omega}\right|_{\omega=0} < 0 \tag{66}$$

$$\left.\frac{dV_H}{d\omega}\right|_{\omega=0} > 0, \quad \left.\frac{dV_F}{d\omega}\right|_{\omega=0} < 0 \tag{67}$$

7.3.2 "Carrot-Carrot" Scenario

Following the same strategy as under autarky we obtain

$$M_i = \frac{(1-\Omega(\phi^*_{br,i}))\mu L}{\sigma F_{br} J_i (1-\omega^2)} \left[p_{br}(\phi^*_{br,i})^{1-\sigma}(1-\gamma_i T) - \omega p_{br}(\phi^*_{br,j})^{1-\sigma}(1-\gamma_j T)\right], i = H, F \tag{68}$$

Free entry and non-arbitrage conditions are represented as

$$\begin{aligned} &F_{br}(\phi^*_{br,i})^{1-\sigma}\int_{\phi^*_{br,i}}^{\infty}\phi^{\sigma-1}d\Omega(\phi) + (F_{gr}-F_{br})(\phi^*_{gr,i})^{1-\sigma}\int_{\phi^*_{gr}}^{\infty}\phi^{\sigma-1}d\Omega(\phi) \\ &- F_{br}[\Omega(\phi^*_{gr,i}) - \Omega(\phi^*_{br,i})] - F_{gr}[1-\Omega(\phi^*_{gr,i})] = F_e \end{aligned} \tag{69}$$

$$\begin{aligned} &[\mu L(1-\gamma_i T)P_i^{\sigma-1} + \gamma_i \mu L T P_{gr,i}^{\sigma-1}]p_{gr}(\phi^*_{gr,i})^{1-\sigma} \\ &- \mu L(1-\gamma_i T)P_i^{\sigma-1}p_{br}(\phi^*_{gr,i})^{1-\sigma} = F_{gr} - F_{br}, \end{aligned} \tag{70}$$

where

$$P_i^{1-\sigma} = \frac{\mu L}{\sigma F_{br}} p_{br}(\phi^*_{br,i})^{1-\sigma}(1-\gamma_i T) \tag{71}$$

$$\begin{aligned} P_{gr,i}^{1-\sigma} = \frac{\mu L}{\sigma F_{br}(1-\omega^2)} &\left[\frac{J_{gr,i}}{J_i}\left[p_{br}(\phi^*_{br,i})^{1-\sigma}(1-\gamma_i T) - \omega p_{br}(\phi^*_{br,j})^{1-\sigma}(1-\gamma_j T)\right]\right. \\ &\left. + \omega\frac{J_{gr,j}}{J_j}\left[p_{br}(\phi^*_{br,j})^{1-\sigma}(1-\gamma_j T) - \omega p_{br}(\phi^*_{br,i})^{1-\sigma}(1-\gamma_i T)\right]\right], \end{aligned} \tag{72}$$

where $J_{gr,i} \equiv \int_{\phi^*_{gr,i}}^{\infty} p_g(\phi)^{1-\sigma} d\Omega(\phi)$.

Accordingly,

$$\left.\frac{d\phi^*_{br,i}}{d\omega}\right|_{\omega=0} < 0, \quad \left.\frac{d\phi^*_{gr,i}}{d\omega}\right|_{\omega=0} > 0, \quad i = H, F, \tag{73}$$

Aggregate emissions

$$\begin{aligned}\mathcal{E}_i = \frac{M_i}{1-\Omega(\phi^*_{br,i})} \Bigg[& \mu L(1-\gamma_i T) P_i^{\sigma-1} \int_{\phi^*_{br,i}}^{\phi^*_{gr,i}} p_{br}(\phi)^{-\sigma} \phi^{-\alpha} d\Omega(\phi) \\ & + \gamma \left(\mu L(1-\gamma_i T) P_i^{\sigma-1} + \gamma_i \mu L T P_{gr,i}^{\sigma-1}\right) \int_{\phi^*_{gr,i}}^{\infty} p_{gr}(\phi)^{-\sigma} \phi^{-\alpha} d\Omega(\phi) \Bigg]\end{aligned} \tag{74}$$

Indirect utility

$$V_i = (1-T) L P_i^{-\mu} \tag{75}$$

Then if $\gamma_H = \gamma_F$,

$$\left.\frac{d\mathcal{E}_i}{d\omega}\right|_{\omega=0} < 0, \quad \left.\frac{dV_i}{d\omega}\right|_{\omega=0} > 0, \quad i = H, F \tag{76}$$

If $\gamma_H < \gamma_F$,

$$\left.\frac{d\mathcal{E}_H}{d\omega}\right|_{\omega=0} < 0, \quad \left.\frac{d\mathcal{E}_F}{d\omega}\right|_{\omega=0} > 0 \tag{77}$$

$$\left.\frac{dV_H}{d\omega}\right|_{\omega=0} < 0, \quad \left.\frac{dV_F}{d\omega}\right|_{\omega=0} > 0 \tag{78}$$

7.3.3 "Stick-Carrot" Scenario

Under a "stick-carrot" scenario let's assume $\{t_H \neq 0, \gamma_H = 0\}$ and $\{t_F = 0, \gamma_F \neq 0\}$. Then masses of firms are represented as

$$M_H = \frac{\mu L(1-\Omega(\phi^*_{br,H}))}{\sigma F_{br}} \frac{T p_{br}(\phi^*_{br,H})^{1-\sigma} - \omega(1-\gamma_F T) p_{br}(\phi^*_{br,F})^{1-\sigma}}{(1-\omega^2) J_H - \mu t_H I_H \sigma^{-1} F_{br}^{-1} p_{br}(\phi^*_{br,H})^{1-\sigma}} \tag{79}$$

$$M_F = \frac{1-\Omega(\phi^*_{br,F})}{J_F} \left[\frac{\mu L(1-\gamma_F T)}{\sigma F_{br}} p_{br}(\phi^*_{br,F})^{1-\sigma} - \omega \frac{M_H}{1-\Omega(\phi^*_{br,H})} \right] \tag{80}$$

Following the same procedure as in two previous cases we obtain the following results

$$\left.\frac{d\phi^*_{br,H}}{d\omega}\right|_{\omega=0} = 0, \quad \left.\frac{d\phi^*_{br,F}}{d\omega}\right|_{\omega=0} < 0 \tag{81}$$

$$\left.\frac{d\phi^*_{gr,H}}{d\omega}\right|_{\omega=0} = 0, \quad \left.\frac{d\phi^*_{gr,F}}{d\omega}\right|_{\omega=0} > 0 \tag{82}$$

$$\left.\frac{d\mathcal{E}_H}{d\omega}\right|_{\omega=0} < 0, \quad \left.\frac{d\mathcal{E}_F}{d\omega}\right|_{\omega=0} > 0 \tag{83}$$

$$\left.\frac{dV_H}{d\omega}\right|_{\omega=0} < 0, \quad \left.\frac{dV_F}{d\omega}\right|_{\omega=0} > 0 \tag{84}$$