Could carbon tariff encourage technology transfer?

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September 3, 2025

Abstract

This paper argues that the introduction of a carbon tariff on dirty goods may influence the decision to transfer technology if consumers hold a strong preference for clean goods and dirty exports negatively affect the foreign environment. With carbon tariffs, dirty production becomes costly for the licensee. By transferring green technology, the licensor raises the licensee's marginal cost, replaces the dirty export market with clean goods, and expands the clean market, making technology transfer profitable for the licensor despite increased competition. The EU has introduced CBAM (Carbon Border Adjustment Mechanism) as a carbon tariff on dirty imports, based on the assumption that such a tariff may incentivise technology transfer. Using a simple duopoly game between a clean domestic producer and a dirty exporter to explore several key findings. First, carbon tariffs on dirty exports can encourage technology transfer when the cross-border impact of dirty exports and the degree of foreign consumers' preference for clean goods are sufficiently high. Second, the licensee prefers only a fixed fee contract for green technology transfer. Third, the licensing incentive tends to rise with the introduction of a carbon tariff as switching to green technology becomes more profitable for the licensee. These findings largely hold under Bertrand competition. However, technology transfer does not occur when bargaining power is shared, regardless of whether a carbon tariff is imposed or not. A key innovation of this paper is the inclusion of two parameters capturing the degree of consumer preference for clean goods and the adoption decision of green technology in the consumer utility function.

Keywords: CBAM, Environmental Damage, Cross-Border Effect, Carbon Tariff, Technology Transfer

1 Introduction

Whether the introduction of a tariff encouraging technology transfer is ambiguous in the literature (Chen et al., 2016; Kim and Lee, 2022; Liu and Mukherjee, 2024; Chang et al., 2022). There is growing evidence of a higher willingness to pay for clean goods and a cross-border impact on the foreign environment of dirty production in the context of trade. These two issues, which are often ignored in the literature, must influence the incentive for technology transfer. This paper aims to investigate the effect of the carbon tariff, as an instrument to discourage dirty exports, particularly in the presence of cross-border effects and higher willingness to pay for clean goods. While the pressing issue of carbon emissions and their detrimental environmental impacts, especially after COVID-19, that poses a critical threat to the sustainable future of our planet is being addressed by the national strategies for zero-carbon emission, the international trade of dirty goods remains a significant source of carbon leakage in the global environment. The mitigation needs for this challenge necessitate prompt and decisive measures to reduce CO2 emissions through such trade channels. In the past, many developed economies have adopted stringent unilateral low-carbon environmental policies to address this issue. The European Union Emissions Trading System (EU ETS) is one such policy where a cap is set by the government in terms of emission allowances that limit the quantity of emissions that European firms can emit. Firms can trade these allowances at auctions in the EU carbon market. However, the EU ETS had limited success in the past (De Perthuis and Trotignon, 2014; Skjærseth and Wettestad, 2008), partly because it was used only within the EU and not in other countries. This prompted EU producers to outsource part of their carbon-intensive production to developing countries, which have become increasingly integrated into global value chains over the past decade, owing to less stringent environmental regulations. This resulted in unchanged global emission levels, and carbon leakage persisted.

To address this carbon imbalance, the EU nations have implemented CBAM (Carbon Border Adjustment Mechanism), a policy specifically designed to discourage carbon imports from developing countries (Mörsdorf, 2022). It involves imposing carbon tariffs on the import of carbon-intensive goods, which would encourage the export of clean goods.

The CBAM aims to eliminate market distortions and prevent carbon leakage (Mörsdorf, 2022; Zhong and Pei, 2022). Recently, Liu et al. (2025) studied the investment behaviour of Chinese firms using a difference-in-differences model on panel data from 2011 to 2022. They observed that CBAM significantly increased greenfield investments abroad by affected Chinese listed firms, driven by two main mechanisms: namely, a trade restructuring effect (as firms redirected exports and operations in response to carbon costs) and an innovation-driven demand effect (through increased $R\&D$ and low-carbon technology development). Their finding provides support for the idea that CBAM corrects carbon cost imbalances between developing and developed country producers and acts as a catalyst for green innovation and technology transfer, indirectly enhancing EU competitiveness by encouraging cleaner production methods. But, a typical firm in a developing world would face capital constraints for the adoption of green technology and hence depend on the technology transfer from foreign competitors. The question is whether the policy would encourage the technology transfer.

Theoretical studies on welfare-maximising import tariffs reveal ambiguous outcomes for technology transfer, licensing and emissions. One strand of literature suggests that such tariffs either fail to facilitate technology transfer altogether or result in its ineffective implementation. For instance, Chen et al. (2016) using a two-country Cournot duopoly model showed that a high enough welfare-maximising tariff can unintentionally lead to ineffective technology transfer. In their model, they demonstrated that high tariffs can encourage foreign firms to license their superior technology to domestic firms, while it would itself switch to an inferior technology for its own production, leading to counterproductive technology transfer. Kim and Lee (2022) showed that under a two-part licensing contract that combines a fixed fee with royalty, the decision to license is dependent upon welfare-maximising tariff and emission tax levels. However, welfare may increase or not depending on royalty constraints, indicating that licensing does not always lead to meaningful technology transfer. Political distortions created by lobbying further cloud the link between welfare-maximising tariffs and effective technology transfer Liu and Mukherjee (2024), while under some settings licensing green technologies ironically increases total pollution and decreases domestic welfare, depending on emissions intensities and technology quality (Chang et al., 2022). While another strand of literature shows that such tariffs facilitate technology transfer. For instance, Kabiraj and Marjit (2003) using a partial equilibrium framework with oligopolistic competition between a domestic firm and a foreign firm showed that such tariffs encourage the foreign firms to transfer their advanced technology to the rival domestic firm, ultimately benefiting consumers and the domestic economy. Consistent with this, Mukherjee and Pennings (2006) demonstrates that a foreign firm holding exclusive rights to an advanced technology is better off transferring technology to a domestic rival firm under competitive market conditions than retaining monopoly power while facing import tariffs. They showed that tariffs, when used strategically, can induce technology transfer through licensing and promote market competition.

While analysis of welfare maximising tariffs often produces ambiguous outcomes for technology transfer, licensing and emissions, carbon-specific border measures such as carbon tariffs and carbon taxes demonstrate stronger potential to curb leakage and promote green technology transfer and innovation. In a recent study, Christoph et al. (2021) using multi-region input–output and computable general equilibrium modelling showed that carbon tariffs can significantly reduce carbon emissions leakage compared to standard tariffs. They emphasised that a tariff's effectiveness in reducing carbon leakage depends on how a tariff internalises environmental costs, not just welfare gains. In this regard, carbon tariff succeeds in internalising emission targets while standard tariffs fall short. Acemoglu et al. (2016) developed an endogenous growth model where clean and dirty technologies compete in the production process. They argued that when dirty technologies are more economical, the technology shift to clean production can be challenging. However, carbon taxes and $R\&D$ subsidies can facilitate the shift towards production and innovation in clean technologies. Böhringer et al. (2016) demonstrated that imposing carbon tariffs on direct and indirect carbon emissions in commodities from nations without domestic emission controls can effectively limit carbon emissions. They also showed that carbon leakage can be reduced by incentivising manufacturers to invest in green technology. Even though the results of the study showed that carbon-specific border measures reduce carbon emissions and encourage manufacturers to invest in green technologies, these results are incomplete because they do not take into account transboundary effects and consumer preferences for clean goods.

There is growing evidence of willingness to pay for clean goods and cross-border environmental damages in both theoretical and empirical literature. But the existing studies did not look at those issues in the context of technology transfer in response to the carbon tariff. Studies consistently show that consumers are willing to pay more for clean goods. Zheng et al. (2022) showed that green advertising appeals raised consumers' willingness to pay a premium for certified green agricultural goods in China, implying consumers are willing to pay more for clean alternatives. Consistent with this is a case study that studied consumer willingness to pay more for sustainable products regarding eco-labelled tuna steak, showing that on average, consumers were willing to pay about a 10% premium for the eco-labelled product in their sample Zhou et al. (2016). In a case study that focused on Portuguese Gen-Z consumers, it was shown that environmental concern, coupled with perceived green quality, and future green vision significantly increased their willingness to pay more for green products (Gomes et al., 2023). Kim et al. (2019) empirically showed that due to greenhouse gases associated with the use of fossil fuels for energy generation, South Korean consumers are willing to pay significant premiums for smartphones produced using renewable energy or green processes. Such findings highlight the importance of aligning trade policies with consumer-driven demand for clean goods. Moreover, the production of carbon-intensive dirty goods contributes to trans-boundary environmental damage, causing global warming and acid rain, disrupting ecosystems, and posing various health hazards. For this reason imports are often subjected to quality check at sea ports of importing countries specially developed ones. These cross-border impacts are equally important in the literature for framing trade policies. For instance,Marjit and Mukherjee (2023) showed that if importing countries experience lower trans-boundary emissions compared to domestically produced emissions, they might be incentivised to import dirty goods. This could be achieved through import subsidies or less stringent tariffs, aiming to reduce their own emissions. This paper shows that trans-boundary pollution plays a vital role in shaping trade policy.

A central contribution of this paper is the incorporation of two parameters into the consumer utility function - (a) consumer preferences for clean goods and (b) cross-border environmental damages - applied in the context of a strategic game of technology transfer. These factors have been overlooked in the existing literature cited above, yet they may have distinct implications for technology transfer, which this paper seeks to investigate. The stages of our game and licensing structure are inspired by Mukherjee and Pennings (2006) and other related literature (Cao et al., 2023; Erkal, 2005; Kabiraj and Marjit, 2003; Kim and Lee, 2022), but our paper is different in several ways. Firstly, they largely model a foreign monopoly with exclusive rights to superior technology, an assumption we cannot adopt. In our setup, the domestic firm owns the superior green technology, while the foreign firm relies on dirty technology. Secondly, they examine standard welfare-maximising import tariffs, whereas we focus on carbon tariffs specifically designed to reduce emissions leakage. Thirdly, their results are dependent upon whether the government sets the tariff before or after licensing, while ours remain unchanged because we assume all firms hold complete information. Finally, we extend the story by exploring the incentivising effect of carbon tariffs on technology transfer among firms, focusing on trans-boundary impact and consumer preference for clean goods, which was missing in the conventional literature on licensing.

This paper analyses a simple Cournot duopoly between a clean producer located in the North and a dirty exporter from the South, competing in the Northern goods market[1]. The imposition of a carbon tariff affects the prices and profits of the firms involved in trade; consequently, optimal license fees and incentives for technology transfer also change. Assuming complete information, both firms are fully informed about market demand, cost structures, and strategic choices, which ensures that our results hold regardless of whether the northern country commits to its tariff before or after licensing. The findings from our paper suggest that technology licensing can facilitate the adoption of green technology by exporters, contributing to emission reduction.

The subsequent sections of this paper are organised as follows: Section 2 outlines the model structure. Section 3 discusses the baseline scenario, while Section 4 determines the optimal licensing fee under a carbon tariff. Section 5 offers a thorough analysis of the model with alternative assumptions. Finally, Section 6 offers concluding remarks.

[1] We use the North-South framework to highlight that firms in Southern economies largely comprises of developing countries that often face financial constraints that limit access to green technology and restrict their capacity for $R\&D$ investment.

2 Model Setting

Using a simple duopoly framework with segmented markets, we want to investigate how carbon tariffs imposed by a developed northern economy impact exports of a developing southern economy if the consumers are willing to pay more for clean goods and the dirty production damages of the foreign environment. The framework considers a world divided into two countries: the northern developed country, home to the local producer, and the southern developing country, which serves as the exporter. Each country has a single firm producing final goods. Firm 1, situated in the northern developed country, possesses sufficient financial resources to invest in R&D and manufacture clean goods using eco-friendly green technology, with a positive marginal cost per unit c, where $c > 0$. By contrast, Firm 2, in the southern developing country, operates under financial constraints, lacks access to such technology, and produces high-carbon-intensive "dirty" goods at zero marginal cost. The key distinction between the firms lies in their production technologies and consumers' preference for clean goods resulting from climate change and increasing global pollution. Both firms compete as Cournot duopolists in the northern market under a complete information framework, catering to consumers there. Although consumers in both regions consume both types of goods, the analysis focuses on northern consumers only. Because we are looking at conditions under which carbon tariffs on imported dirty goods might encourage northern firms in developed economies to transfer green production technology through licensing to firms in developing regions—potentially mitigating trans-boundary environmental damage and aligning with rising consumer preferences for clean goods.

2.1 Consumer and Clear Goods Preference

The utility function of the northern consumer is built on a strictly concave form, adopted by a large body of literature (Singh and Vives, 1984; Häckner, 2000; Sen et al., 2021), but it introduces heterogeneous preferences for clean and dirty goods. Assuming the northern consumers consume quantities q_1 and q_2 of clean and dirty goods from Firms 1 and 2, respectively, along with a composite good I. The utility function is then specified as:

$$U(q_1, q_2, I) = (a + \lambda)q_1 + (a + \lambda x)q_2 - \frac{1}{2}[q_1^2 + q_2^2 + 2q_1q_2] + I \; ; \; \lambda > 0, \; \text{x} = 0 \text{ or } 1 \quad (1)$$

The function incorporates two additional parameters: a continuous variable λ, where $\lambda > 0$, capturing the degree of consumer preference for clean goods, and a binary variable x, indicating Firm 2's adoption of green technology[2]. When $\lambda = 0$, consumers exhibit neutrality between clean and dirty goods; a positive value of λ signals a growing preference for clean goods. As λ rises, this bias intensifies. The binary variable $x = 1$ if Firm 2 adopts green technology to produce clean goods, and zero if it continues with carbon-intensive production. Therefore, the interaction term '$\lambda.x$' represents the extent to which northern consumers' demand for Firm 2's good is shaped by both the adoption of green technology and their preference for a clean good. Consumers maximise utility subject to the budget constraint $p_1q_1 + p_2q_2 + I \leq M$, where p_1, p_2 and M denote prices of good 1 and 2 and income of a representative northern consumer, respectively. This provides us with the optimal prices for final good 1 and good 2 as follows:

$$p_1 = a + \lambda - q_1 - q_2 \tag{2}$$

$$p_2 = a + \lambda x - q_1 - q_2 \tag{3}$$

To ensure the production of positive quantities for both goods, it is standard to assume, without loss of generality (WLOG), that $a > c > 0$. This means that the market size must be greater than the marginal cost of producing the good.

Our utility function differs from the one used by the existing literature (Singh and Vives, 1984; Häckner, 2000; Sen et al., 2021), which considers horizontal and vertical product differentiation and their impact on consumer utility. In contrast, our utility function highlights how rising consumer preferences for clean goods, driven by concerns over climate change and increasing global pollution, have led to a higher demand for clean goods. This shift in demand has also expanded the market size through increased prices for clean goods. The firms exhibit identical inverse demand functions and hence $p_1 = p_2$ at equilibrium under two distinct scenarios. First, when consumers hold neutral preferences, then it does not matter what type of good firm 2 is producing, that is $\lambda = 0$ and x can be 0 or 1 and second, when when consumers strictly prefer clean goods and both firms produce clean goods, that is both λ and x are equal to 1. In both cases, clean

[2]Technology choice is assumed to be binary in the model. Therefore, willingness to pay should be reflected in the size of demand, specifically in the intercept, which essentially influences the market price.

and dirty goods are valued equally by consumers. However, for positive values of λ and for $x = 1$, the prices p_1 and p_2 not only diverge but are also higher than when a consumer is indifferent between clean and dirty goods. As a result, the inverse demand functions for both firms shift upwards, indicating a higher willingness to pay for clean goods as consumer preference for clean goods increases. This increased preference for clean goods also expands the market size from $2a$ to $2(a+\lambda)$. These two forces are driving our results and bring a set of different results from the existing results on licensing.

2.2 Environmental Damage and Cross-Border Effect

As Firm 2 uses dirty technology to produce good 2, it is assumed that each unit produced by Firm 2 results in one unit of carbon emissions domestically. Meanwhile, the environmental damage (d) caused by good 2 from the export of dirty goods to the northern developed country can be specified as follows:

$$d = \alpha(1 - x)(q_2)^2 \tag{4}$$

Here, α represents the degree of cross-border impact, ranging from 0 for no pollution transfer to 1 for complete impacts. The binary variable x indicates the adoption of eco-friendly green production technology by Firm 2. The quantity q_2 represents the amount of good 2 exported to the northern developed country. The function increases quadratically with q_2, indicating that environmental damage escalates rapidly with higher import volumes of dirty goods. As x equals 1, the environmental damage in the cross-border economy becomes zero, showing that the adoption of eco-friendly green technology by Firm 2 effectively lowers environmental damage. When α is 0, there is no cross-border pollution, making the damage zero regardless of x and q_2. Conversely, when α is 1, the damage function reflects the full extent of pollution transfer. This function ensures non-negative values, emphasising that environmental damage cannot be negative and highlights how both the decision to adopt (or not adopt) green technology and the volume of dirty-goods imports jointly determine cross-border environmental impacts. Existing literature uses similar quadratic environmental damage functions (Marjit and Mukherjee, 2023; Xu et al., 2016; Lai and Hu, 2008), but our function incorporates the impact of eco-friendly technology adoption as well.

Due to the detrimental environmental impact of increasing global emissions, consumers are now more aware of the negative consequences associated with carbon-intensive products. This heightened awareness has resulted in a growing preference for cleaner alternatives, leading to an expanding market for environment-friendly goods. Consequently, firms producing these clean goods experience increased sales and can derive higher prices, reflecting consumers' willingness to pay a premium for products that contribute less to global pollution. This trend is clearly illustrated in our model, where consumers are willing to pay a higher price for clean good 1 compared to dirty good 2. As a result, Firm 1, which produces clean goods, is gaining market share over Firm 2 producing carbon-intensive dirty goods.

In this paper, we examine conditions under which both firms find themselves in mutually beneficial situations, preferring to transfer green technology to Firm 2 and whether the carbon tariff encourages them to do so. We begin with a baseline scenario where Firm 2 is able to export its dirty goods to foreign consumers without having to pay any fees related to its carbon emissions. In this setting, we analyse two possible licensing structures: a two-part contract combining a per-unit royalty r and a fixed fee L and a simpler alternative involving a one-time lump-sum payment. We later demonstrate that royalty-based licensing cannot be part of the optimal contract in the absence of a carbon tariff. This is due to the distortionary effect of the per-unit royalty; it raises Firm 2's marginal cost, reduces output, and diminishes profits of both firms, thereby weakening incentives to adopt green technology. The imposition of a carbon tariff amplifies these distortions by further penalising production, rendering the two-part licensing scheme even less viable. Thus, only a fixed-fee licensing contract remains optimal. Subsequently, we analyse a scenario where the foreign country imposes a carbon tariff on imports of dirty goods. In this context, we again identify the optimal licensing fee required for Firm 2 to access Firm 1's green technology.

3 Optimal licensing without carbon tariff

In this section, we analyse two licensing schemes in the absence of a carbon tariff:

- We first consider a combined per-unit royalty and fixed-fee license, whereby Firm 1 transfers its eco-friendly production technology to Firm 2 in exchange for a royalty r per unit plus a lump-sum licensing fee L. We then assess Firm 2's decision to accept or reject this offer.

- Next, we examine a fixed fee licensing only arrangement in which Firm 1 licenses the technology to Firm 2 for a single, upfront payment.

We consider the following game. In stage 1, Firm 1 offers Firm 2 a take-it-or-leave-it licensing contract under two possible arrangements: a two-part scheme combining a per-unit royalty r with a fixed fee L, or a fixed-fee-only arrangement involving a one-time lump-sum payment. Firm 2 subsequently decides whether to adopt the eco-friendly green technology. In stage 2, the firms compete in the northern goods market as Cournot duopolists. We solve all the staged games through backwards induction.

We begin by examining the scenario where firm 1 offers a two-part licensing contract to firm 2. Based on the demand functions (equations 2 and 3 from the preceding section), the respective profit maximisation problems faced by firm 1 and firm 2 in stage 2—assuming firm 2 declines the offer are as follows:

$$\max_{q_1} \pi_1^{NT} = (a + \lambda - q_1 - q_2 - c)q_1 \tag{5}$$

$$\max_{q_2} \pi_2^{NT}(a - q_1 - q_2)q_2 \tag{6}$$

We obtained the following optimal Nash-Cournot quantities of good 1 and good 2 as functions of λ.

$$q_1^{NT} = \frac{1}{3}(a + 2\lambda - 2c) \tag{7}$$

$$q_2^{NT} = \frac{1}{3}(a - \lambda + c) \tag{8}$$

From equations (7) and (8), we can clearly see that $q_1^{NT} > 0$ and $q_2^{NT} > 0$ for $\frac{2c-a}{2} < \lambda < a + c$. Substituting values of q_1^{NT} and q_2^{NT} back into profit functions of the firms, we obtained $\pi_1^{NT} = 1/9(a + 2\lambda - 2c)^2$ for firm 1 and $\pi_2^{NT} = 1/9(a - \lambda + c)^2$ for firm 2, where superscript 'NT' denotes the scenario before technology transfer i.e $x = 0$.

Lemma 1 *Under complete information and trade without a carbon tariff, the local producer produces clean goods and the foreign firm exports dirty goods if and only if the consumer preference parameter* λ *satisfies:* $\frac{2c-a}{2} < \lambda < a + c$.

If firm 2 accepts the offer and adopts green technology, then $x = 1$ and the respective profit maximisation problems faced by firm 1 and firm 2 in stage 2 are as follows:

$$\max_{q_1} \pi_1^{TT} = (a + \lambda - q_1 - q_2 - c)q_1 + rq_2 + L_1 \quad (9)$$

$$\max_{q_2} \pi_2^{TT} = (a + \lambda - q_1 - q_2 - c - r)q_2 - L_1 \quad (10)$$

We obtained the following optimal Nash-Cournot quantities of good 1 and good 2 as functions of λ and r.

$$q_1^{TT} = \frac{1}{3}(a + (\lambda - c) + r) \quad (11)$$

$$q_2^{TT} = \frac{1}{3}(a + (\lambda - c) - 2r) \quad (12)$$

using equations (11) and (12), we can see that $q_1^{TT} > 0$ for $\lambda > c$ and $q_2^{TT} > 0$ for $r > \dfrac{a + \lambda - c}{2}$. Substituting these equilibrium outputs q_1^{TT} and q_2^{TT} back into the firms' profit functions gives $\pi_1^{TT} = 1/9(a+\lambda+r-c)^2$ for firm 1 and $\pi_2^{TT} = 1/9(a+\lambda-c-2r)^2$ for firm 2, where superscript 'TT' denotes the post technology transfer scenario. In the first stage, Firm 2 accepts the licensing agreement if and only if $\pi_2^{TT} \geq \pi_2^{NT}$. Thus the maximum fee that firm 1 can charge from firm 2 is the amount that will make firm 2 just indifferent between adopting technology and not adopting and since firm 1's profit is increasing in L_1, it chooses: $L_1 = \pi_2^{TT} - \pi_2^{NT} = (4/9)(a - r)(\lambda - c - r)$. For $L_1 > 0$, the conditions $a > r$ and $(\lambda - c) > r$ must hold; otherwise, firm 2 would not accept the offer and would prefer its zero-cost, carbon-intensive technology. Finally, substituting q_1^{TT},q_2^{TT} and L_1 into firm 1's profit and maximising with respect to r yields the optimal royalty rate given by $r^* = 1/2(a + \lambda - c)$. However, at this royalty level one finds $q_2^{TT} = 0$ indicating that royalty licensing does not support technology transfer and thus cannot be part of the optimal licensing strategy. However, if the licensor offers a fixed-fee licensing contract, technology transfer does occur, with the optimal licensing fee given by $L_1^* = \dfrac{4}{9}a(\lambda - c)$. This leads to the following proposition:.

Proposition 1 *In a regime without carbon tariffs and with firm 1 exercising full bargaining power, the only way to induce technology transfer to firm 2 is through a fixed-fee license ($L_1^* = \dfrac{4}{9}a(\lambda - c)$ and $r^* = 0$). Such a contract is profit-enhancing for firm 1 and firm 2 under the conditions $c < \lambda < c + \dfrac{2a}{3}$.*

The intuition of the above result is the following. When firm 1 holds all the bargaining power, it can set the royalty so high that it effectively captures the entire surplus generated by green-technology adoption, leaving firm 2 with no net benefit from switching. With its profit margin wiped out, firm 2 optimally chooses not to produce the clean good, so technology transfer fails to occur under any positive royalty. The only way to sustain adoption is to set $r^* = 0$. Plugging $r^* = 0$ back into the two-part licensing arrangement converts it into a pure fixed-fee arrangement with $L_1^* = \frac{4}{9}a(\lambda - c)$. Finally, Firm 1 will offer the fixed-fee licensing contract only if it raises its own profit, that is, $\pi_1^{TT} > \pi_1^{NT}$, which always holds under the condition $\lambda < a+c$. However, if the marginal cost associated with green technology adoption exceeds the degree of consumer preference for clean goods, technology transfer will not take place. This outcome arises because, in the absence of carbon tariffs, Firm 2 can export its pollution-intensive goods to a northern developed country without incurring any carbon-related costs. It faces zero marginal production costs and avoids payments for carbon emissions, thereby gaining a cost advantage. As a result, Firm 2 can compete effectively by continuing to produce dirty goods, achieving higher profitability provided its production efficiency outweighs the degree of consumer preference for clean goods.

Erkal (2005) lends support to our proposition. Using a theoretical model, they analyze the policy implications of licensing between firms producing differentiated goods. Their findings suggest that when the degree of product differentiation is sufficiently low, technology transfer does not occur under two-part licensing or fixed royalty contracts. However, their analysis does not consider fixed-fee licensing or the role of consumer preferences for clean goods and cross-border impacts in shaping the licensing incentives of firms producing homogeneous goods with different production technologies. Our model addresses this gap by incorporating these factors directly into the consumer's utility function.

4 Optimal licensing under carbon-tariff

We begin with the fixed-fee licensing contract since its already being established in the previous section that royalty cannot be part of a licensing contract. The key distinction here is that, unlike the earlier cases, Firm 2 now faces a per-unit carbon tariff t on the export of carbon-intensive dirty goods.

In this section, we analyze the following sequential game consisting of three stages. In stage 1, Firm 1 offers Firm 2 a take-it-or-leave-it fixed fee licensing contract. Firm 2 then decides whether to accept or reject the contract offered. If the offer is accepted, both firms produce clean goods, environmental damage is nullified, and the game proceeds directly to stage 3. If Firm 2 rejects the offer, we move to stage 2. Stage 2 introduces a per-unit carbon tariff t imposed on Firm 2's exports of carbon-intensive goods. This tariff is set by an independent authority in the northern developed country, whose aim is to determine the optimal rate that minimizes environmental harm from dirty imports. Accordingly, the country's social welfare is defined as tariff revenue net of the cross-border environmental damage caused by production of dirty goods. In stage 3, regardless of the path taken, both firms compete in the northern market as Cournot duopolists. The entire game is solved using backward induction to identify equilibrium strategies at each stage.

Consider the scenario in which Firm 1 offers Firm 2 a fixed fee licensing contract under a carbon-tariff regime. Using the inverse demand functions from equations (2) and (3) in section 3.1, the respective profit maximisation problems faced by firm 1 and firm 2 in stage 2, assuming firm 2 declines the offer, are as follows:

$$\underset{q_1}{max}\ \pi_1^{NT} = (a + \lambda - q_1 - q_2 - c)q_1 \tag{13}$$

$$\underset{q_2}{max}\ \pi_2^{NT}(a - q_1 - q_2 - t)q_2 \tag{14}$$

We obtained the following optimal Nash-Cournot quantities of good 1 and good 2 as functions of λ and t.

$$q_1^{NT} = \frac{1}{3}(a + 2(\lambda - c) + t) \tag{15}$$

$$q_2^{NT} = \frac{1}{3}(a - \lambda + c - 2t) \tag{16}$$

From equations (15) and (16), it is evident that for a given t, both $q_1^{NT} > 0$ and $q_2^{NT} > 0$ hold when $c - \frac{a+t}{2} < \lambda < a + c - 2t$. Alternatively, the condition for $q_2^{NT} > 0$ can be expressed in terms of carbon tariff t for a given λ, such that t lies within the range $0 < t < \frac{a - \lambda + c}{2} = t_p$. The upper bound of this range, $t_p = \frac{a - \lambda + c}{2}$, represents the prohibitive tariff-the point at which the quantity exported for good 2 becomes zero.

Firm 2 earns positive profits for any tariff below t_p, but once the tariff exceeds this level, both its output and profits drop to zero. Substituting values of q_1^{NT} and q_2^{NT} back into profit functions of the firms, we obtained $\pi_1^{NT} = \frac{1}{9}(a + 2\lambda - 2c + t)^2$ for firm 1 and $\pi_2^{NT} = 1/9(a - \lambda + c - 2t)^2$ for firm 2, where superscript 'NT' denotes the scenario before technology transfer i.e $x = 0$.

Lemma 2 *Under complete information and trade with carbon tariff t, both firms produce positive quantities if and only if the consumer preference parameter* λ *satisfies* $c - \dfrac{a+t}{2} < \lambda < a + c - 2t$*, for a given t.*

At stage 2, an autonomous regulatory body of the northern country imposes a carbon tariff t on each unit of imports from Firm 2. Its objective is to identify the optimal tariff rate that minimises the environmental impact of carbon-intensive imports. To reflect this goal, the government's welfare function is defined as the tariff revenue collected minus the cross-border environmental damage resulting from the production of good 2 in the southern country. The welfare function is therefore represented by the following equation:

$$W = \underbrace{tq_2^{NT}}_{\textit{Carbon Tariff Revenue}} - \underbrace{\alpha(q_2^{NT})^2}_{\textit{Cross-Border Environmental Damage}} \tag{17}$$

The optimal carbon tariff that maximizes government welfare is given by $t^* = \frac{(4\alpha+3)(a-\lambda+c)}{8\alpha+12}$, and is strictly positive whenever $\lambda < a + c$. This tariff must be lower than the prohibitive level, since setting the tariff at or above the prohibitive point causes Firm 2's output to drop to zero, eliminating tariff revenue entirely. Because the government's welfare accounts for both cross border environmental damage and tariff revenue, retaining a portion of imports is essential to maintain fiscal benefits. Therefore, $t^* < t_p$, which implies $\frac{(3+4\alpha)(a-\lambda+c)}{12+8\alpha} < \frac{a-\lambda+c}{2}$; this inequality holds for all $\alpha\epsilon[0, 1]$.

Differentiating optimal carbon tariff t^* with respect to α and λ, we find that the optimal tariff increases with the degree of cross-border impact (α) and decreases with consumer preference for clean goods (λ). That is, greater cross-border pollution intensity justify higher border adjustments, while stronger domestic demand for clean goods reduces the need for such tariffs. These comparative-statics results are consistent with findings in the literature. For instance, it has been shown by Böhringer et al. (2021) that carbon border tariffs rise with larger cross-border externalities and fall with increasing green demand elasticities. Similarly, Brunel and Levinson (2024) confirm in a partial-equilibrium setting that higher leakage parameters necessitate steeper tariffs, whereas stronger preferences for clean goods lower the optimal tariff level.

Substituting the value of optimal carbon tariff back into the firms' profit functions gives $\pi_1^{NT} = \frac{(a(4\alpha+5)-(4\alpha+7)(c-\lambda))^2}{16(2\alpha+3)^2}$ and $\pi_2^{NT} = \frac{(a+c-\lambda)^2}{4(2\alpha+3)^2}$.

At stage 3, assuming firm 2 accepts the licensing offer , the respective profit maximization problems faced by firm 1 and firm 2 are as follows:

$$\underset{q_1}{max}\ \pi_1^{TT} = (a + \lambda - q_1 - q_2 - c)q_1 + L_2 \tag{18}$$

$$\underset{q_2}{max}\ \pi_2^{TT} = (a + \lambda - q_1 - q_2 - c)q_2 - L_2 \tag{19}$$

We obtained the following optimal Nash-Cournot quantities of good 1 and good 2 as functions of λ:

$$q_1^{TT} = \frac{1}{3}(a + \lambda - c) \tag{20}$$

$$q_2^{TT} = \frac{1}{3}(a + \lambda - c) \tag{21}$$

As shown in equations (20) and (21), these outputs are positive provided $\lambda > c - a$. Substituting these equilibrium outputs q_1^{TT} and q_2^{TT} back into the firms' profit functions gives $\pi_1^{TT} = \frac{1}{9}(a + \lambda - c)^2 + L$ for firm 1 and $\pi_2^{TT} = \frac{1}{9}(a + \lambda - c)^2 - L$ for firm 2. The superscript 'TT' indicates the post–technology transfer scenario, where both firms produce clean goods, eliminating cross border environmental damage. In this scenario, stage 2 where the government imposes a carbon tariff, is skipped entirely. In stage 1, Firm 2 will accept the licensing contract only if $\pi_2^{TT} \geq \pi_2^{NT}$. The maximum fixed fee L_2 that firm 1 can charge, while keeping firm 2 indifferent between adopting and not adopting green technology, is: $L_2^* = \pi_2^{TT} - \pi_2^{NT} = \frac{1}{9}(a - c + \lambda)^2 - \frac{(a+c-\lambda)^2}{4(2\alpha+3)^2}$. Technology transfer will happen for $L_2^* > 0$ which always holds for all values of $\alpha\epsilon[0, 1]$.

Finally, to identify the threshold carbon tariff level, denoted by t^{**}, at which firm 2 is indifferent between producing with dirty technology or switching to clean production, we set its post-transfer and pre-transfer profits equal:$\pi_2^{TT} - \pi_2^{NT}|_{t=t^{**}} = 0$. Solving this yields the threshold tariff $t^{**} = t^* = \frac{(4\alpha+3)(a-\lambda+c)}{8\alpha+12} < t_p$ which is strictly less than the prohibitive tariff t_p. This leads to the following proposition.

Proposition 2 *Under a fixed fee licensing contract where the fee is* $L_2 = \frac{1}{9}(a-c+\lambda)^2 - \frac{(a+c-\lambda)^2}{4(2\alpha+3)^2}$ *the following results hold:*

1. *The threshold carbon tariff* $t^{**} = \frac{(4\alpha+3)(a-\lambda+c)}{8\alpha+12} < t_p$ *coincides with the welfare-maximizing optimum tariff rate* t^* *and satisfies* $t^* < t_p$.

2. *For* $0 < t < t^{**} = t^*$ *, firm 2 prefers dirty production and rejects the licensing contract.*

3. *For* $t^{**} = t^* < t < t_p$*, it accepts the contract, adopts green technology, and switches to producing clean goods.*

The intuition of the above result is the following. The government's welfare function trades off tariff revenue against environmental harm, so the optimal tariff t^* is where the marginal revenue from one more unit taxed equals the marginal environmental damage reduction benefit. That exact rate also makes firm 2's net profit from dirty production (after paying the tariff) equal its net profit from clean production (after the license fee), so it's firm 2 indifference point. If $t < t^*$, firm 2 finds dirty production more cost-effective since the carbon tariff costs less than the combined expense of adopting clean technology, incurring higher marginal production costs, and paying the license fee. If $t > t^*$ (but below the prohibitive t_p), the tariff makes dirty production too costly, so firm 2 opts to pay the license, adopt green technology, and switch to producing clean goods. Finally, firm 1 will propose the fixed-fee licensing agreement only if it raises its own profit, which is conditional upon $c + \frac{9-4\alpha}{21+4\alpha} < \lambda < c - \frac{3+4\alpha}{9+4\alpha}$.

4.1 Effects of consumer preferences and Cross-border impacts

We begin by analyzing how the fixed license fee for transferring green technology changes across different regimes. In the absence of a carbon tariff, the license fee increases with λ, but remains independent of α. Under a carbon tariff regime, however, the license fee increases with both λ and α. Further, on comparing license fee under carbon tariff ($L_2^* = (\frac{a+\lambda-c}{3})^2 - (\frac{a-\lambda+c}{2(2\alpha+3)})^2$) with license fee without a carbon tariff ($L_1^* = (\frac{a+\lambda-c}{3})^2 - (\frac{a-\lambda+c}{3})^2$), we observe that $L_2^* > L_1^*$ will always hold for all $\alpha\epsilon[0,1]$. This yields the following proposition.

Proposition 3 *1. If $t^{**} = t^* < t < t_p$ then licensing incentive rises with the imposition of carbon tariff, that is, $L_2^* > L_1^*$, for all $\alpha \in [0, 1]$.*

2. Without the tariff, licensing incentive responds positively to consumer preferences for clean goods $\frac{\partial L_1^*}{\partial \lambda} > 0$ but is unaffected by cross-border impact $\frac{\partial L_1^*}{\partial \alpha} = 0$.

3. With the tariff, licensing incentive increases with both consumer preferences for clean goods and cross-border impact, that is, $\frac{\partial L_2^*}{\partial \lambda} > 0$, $\frac{\partial L_2^*}{\partial \alpha} > 0$

The intuition of the above result is the following. The imposition of a carbon tariff makes dirty production more expensive, thereby increasing the per-unit cost savings that firm 2 can achieve by adopting green technology and thus makes green technology adoption more attractive and profitable. This outcome is driven by a price effect:-the carbon tariff raises the relative cost of dirty production, increasing the economic appeal of switching to green production technology. Moreover, a fixed-fee licensing arrangement does not influence firm 2's production decisions; firm 1 can extract this entire additional surplus upfront. In essence, the tariff adds to the profitability of adopting green technology, thereby increasing firm 2's willingness to pay, raising the optimal licensing fee to reflect these enhanced gains.

Differentiating the fixed license fee across regimes shows that under the no carbon tariff regime, the optimal fixed fee increases with λ, but remains independent of α. This is because firm 2 is not penalised for dirty production, so α does not influence its cost structure or licensing incentives. In contrast, when consumers strongly prefer clean goods (high λ), firm 2 anticipates higher demand and profits from adopting green technology causing optimal license fee to increase with λ. Under a carbon tariff regime, however, the license fee increases with both λ and α. A higher λ increases firm 2's market valuation of clean technology, while a higher α raises the cost of dirty production due to cross-border environmental penalties in the form of higher carbon tariffs, making the switch to green technology more profitable. As a result, firm 1 can extract a larger surplus through a higher lump-sum license fee.

Empirical evidence from Tangato (2024) provides indirect support to our proposition. Using panel data from 190 countries (2005-2020), they studied how green technology adoption affects global carbon emissions. The authors found that green technology adoption significantly reduces emissions across both developed and developing countries. Since green technologies produce measurable global public goods such as improved air quality and reduced emissions, their social value increases, enhancing the value of the licensed technology. Subsequently, technologies with broader abatement potential warrant higher licensing fees, especially in regions with high cross-border pollution impacts. Moreover, the authors show that consumer access to clean alternatives (such as clean cooking fuels and renewable energy) drives emission reductions. This implies that in markets with greater consumer preference for clean goods, the underlying technology carries higher value, supporting our finding that licensing fees increases with degree of consumer preference for clean goods.

5 Alternative assumptions

5.1 Bertrand Competition

We now examine how outcomes change when firms compete à la Bertrand under complete information—meaning both firms possess full knowledge of market demand, cost structures, and strategic options. Throughout, we assume the northern firm holds full bargaining power.

Firm 1 produces the clean good at a marginal production cost of c. Firm 2's technology adoption is captured by the binary variable x, where $x = 0$ corresponds to dirty production at zero marginal cost and $x = 1$ reflects green production with marginal cost c. The demand functions are defined as follows:

$$q_1(p_1, p_2) = a + \lambda - p_1 + p_2 \tag{22}$$

$$q_2(p_1, p_2) = a + \lambda x - p_2 + p_1 \tag{23}$$

showing that each firm's quantity demanded depends on both its own price and the rival's price. In this section, we examine which licensing arrangement either a two-part licensing or a fixed-fee licensing, is more effective in enabling technology transfer from firm 1 to firm 2, under two distinct policy regimes

- Without a carbon tariff: Same game structure as Section 4, except firms compete as Bertrand duopolists at Stage 2.

- With a carbon tariff: Mirrors Section 5, except that Bertrand competition replaces Cournot at Stage 3.

Given the complete-information setting, the timing of the northern country's tariff commitment (whether before or after the licensing decision) has no bearing on the outcomes.

Our findings align with those presented in Sections 4 and 5 except for the precise levels of the fixed-fee license and tariff. Without any carbon tariff, the only way to induce firm 2's adoption is a fixed-fee license, profit enhancing for both firms when λ lies between $\frac{c}{2}$ and $\frac{-6a+c}{5}$. With a carbon tariff, the welfare-maximizing rate coincides with the threshold tariff: below this level firm 2 rejects the license and stays with dirty production, while between this level and the prohibitive tariff it accepts the fixed fee licensing contract and switches to green production. Crucially, these results hold regardless of whether the northern country commits to its tariff before or after licensing.

5.2 Nash Bargaining

To this point, we have assumed firm 1 holds all the bargaining power in licensing. Now we introduce a generalized Nash bargaining setup to jointly determine the royalty rate 'r' and fixed fee 'L'. In a regime without carbon tariffs, firm 1 offers firm 2 a two-part license, choosing (r,L) to solve:

$$\underset{r,L}{max} \beta log(A) + (1-\beta) log(B) \tag{24}$$

where

$A = \pi_1^{TT}|_{L,r} - \pi_1^{NT}|_{t=0} = \frac{1}{9}\left(a^2 + a(-2c+2\lambda+5r) + c^2 - 2c\lambda - 5cr + \lambda^2 + 9L - 5r^2 + 5\lambda r\right) - \frac{1}{9}(a-2c+2\lambda)^2$

and

$B = \pi_2^{TT}|_{L,r} - \pi_2^{NT}|_{t=0} = \left(\frac{1}{9}(a-c+\lambda-2r)^2 - L\right) - \left(\frac{1}{9}(a+c-\lambda)^2\right).$

Here, A and B are the profit gains to firms 1 and 2 from technology transfer under zero carbon tariff, while β and $1-\beta$ are the bargaining power of firm 1 and 2 respectively. We find that under no carbon tariff regime and with generalized Nash bargaining, both the optimal royalty rate and the fixed licensing fee are equal to zero.

We now examine the scenario of generalized Nash bargaining setup under carbon tariff regime. The maximization problem changes to:

$$\max_{r,L} \beta log(C) + (1-\beta) log(D) \tag{25}$$

where

$C = \pi_1^{TT}|_{L,r} - \pi_1^{NT}|_{t>0} = \frac{1}{9}\left(a^2 + a(-2c + 2\lambda + 5r) + c^2 - 2c\lambda - 5cr + \lambda^2 + 9L - 5r^2 + 5\lambda r\right) - \frac{(a(4\alpha+5) - (4\alpha+7)(c-\lambda))^2}{16(2\alpha+3)^2}$

and

$D = \pi_2^{TT}|_{L,r} - \pi_2^{NT}|_{t>0} = \left(\frac{1}{9}(a - c + \lambda - 2r)^2 - L\right) - \frac{(a+c-\lambda)^2}{4(2\alpha+3)^2}$.

Here, C and d are the profit gains to firms 1 and 2 from technology transfer under carbon tariff regime. We find that under carbon tariff regime and with generalized Nash bargaining, optimal fixed license fee will be zero while optimum royalty rate will be $\tilde{r} = 1/2(a + \lambda - c)$. However, at this royalty level one finds $q_2^{TT} = 0$. This gives us the following proposition:

Proposition 4 *Under generalized Nash bargaining, technology transfer from firm 1 to firm 2 does not take place, regardless of whether a carbon tariff is imposed or not.*

The intuition of the above result is the following. Under generalized Nash bargaining technology transfer doesn't occur regardless of the licensing policy (two part licensing, royalty or fixed fee licensing) and irrespective of whether a carbon tariff is imposed.

Without a carbon tariff, firm 2 faces no cost penalty for dirty production, so its profit from sticking with its current production method remains high. At the same time, shared bargaining power means firm 1 cannot charge royalties or fees large enough to compensate for both the value of its technology and the increased competition it would face after transferring it. The gains from technology transfer under shared bargaining power are too small to satisfy both firms. As a result, no licensing agreement is reached and technology transfer fails.

Even when a carbon tariff is in place, royalties increase the per-unit cost of clean production for firm 2, which discourages it from switch away from cheaper, dirty production. Fixed-fee mechanisms such as royalty or licensing fees, could help preserve licensing incentives, but with shared bargaining power, firm 1 cannot demand a fee high enough to cover both the value of its green technology and the potential profit losses from firm 2 becoming a stronger competitor. Moreover, generalized Nash bargaining requires the total surplus from licensing to be shared; therefore, both firms receive only a portion of the surplus. If that surplus is already constrained by tariffs or output distortions caused by royalties, neither firm finds technology transfer beneficial, and no agreement is reached.

Chen et al. (2021) present results that align with our findings. They analysed how rival firms negotiate green technology licensing under a cap-and-trade system. Their study shows that when firms possess equal bargaining power, the licensor (Firm 1) cannot generate sufficient licensing revenue to offset the competitive disadvantage caused by the licensee's (Firm 2's) cost reduction through green technology adoption. Our model differs from theirs in two ways. First, we focus on a carbon tariff instead of a cap-and-trade system. Second, their model does not account for consumer preferences for clean goods and cross-border impacts that influence licensing incentives among firms. We have incorporated these factors in the consumer's utility function to better understand how they influence technology transfer decisions.

6 Conclusion

This paper contributes to the existing literature by presenting an integrated analysis of carbon border adjustments, technology licensing, and trans-boundary environmental damage within a simple Cournot duopoly setting. This paper finds that first, an appropriately structured carbon tariff, when combined with targeted licensing arrangements such as fixed fee licensing, can serve as an effective instrument to facilitate green technology transfer in conditions where cross-border environmental damage impacts are significant and consumers exhibit a strict preference for clean goods. Second, to ensure widespread adoption of clean technologies, tariff rates must be carefully estimated to surpass the critical indifference threshold to encourage firms to adopt green technologies by making them economically advantageous for firms.

The policy implications of our paper are as follows. First, consumers should be made more aware of the carbon footprint and environmental attributes of goods. This increased awareness will encourage them to pay a premium for clean goods, thereby enabling producers to charge higher prices for eco-friendly clean goods. Second, policymakers must calibrate carbon tariffs to account for the exact amount of negative externality created by the export of dirty goods. Such an integrated approach helps align firms' incentives with the broader environmental objective of emission reduction.

Building on our results and policy implications outlined above, future research could explore how different ways of technology transfer, such as FDI, strategic partnerships between rival firms,$R\&D$ corporations between firms in the value chain, shape the motivations and incentives for both sharing and adopting green technologies. It would also be valuable to explore whether carbon tariffs can effectively encourage technology transfers among firms with incomplete information, or in competitive settings characterised by Stackelberg dynamics.

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Appendix

A Bertrand Competition Results

A.1 Without a carbon tariff

We consider the following game. In stage 1, Firm 1 offers Firm 2 a take-it-or-leave-it licensing contract under two possible arrangements: a two-part scheme combining a per-unit royalty r with a fixed fee L, or a fixed-fee-only arrangement involving a one-time lump-sum payment. Firm 2 subsequently decides whether to adopt the eco-friendly green technology. In stage 2, the firms compete in the northern goods market as bertrand duopolists. We solve all the staged games through backwards induction.

Based on the demand functions (given by equation (22) and (23) in section 5.1), the respective profit maximisation problems faced by firm 1 and 2 in stage 2, assuming firm 2 declines the offer are as follows:

$$\max_{p_1} \pi_1^{NT} = (p_1 - c)q_1 = (p_1 - c)(a + \lambda - p_1 + p_2) \tag{26}$$

$$\max_{p_2} \pi_2^{NT} = (p_2)q_2 = (p_2)(a + p_1 - p_2) \tag{27}$$

We obtained the following optimal Nash-Bertrand prices of good 1 and good 2 as a function of λ:

$$p_1 = a + \frac{2(c + \lambda)}{3} \tag{28}$$

$$p_2 = \frac{1}{3}(3a + c + \lambda) \tag{29}$$

When firm 2 accepts the offer and adopts green technology, then $x = 1$ and the respective profit maximisation problems faced by firm 1 and firm 2 in stage 2 are as follows:

$$\max_{p_1} \pi_1^{NT} = (p_1 - c)q_1 + rq_2 + L \tag{30}$$

$$\max_{p_2} \pi_2^{NT} = (p_2 - c - r)q_2 - L \tag{31}$$

We obtained the following optimal Nash-Bertrand prices of good 1 and good 2 as a function of r and λ:

$$p_1^{TT} = p_2^{TT} = a + c + \lambda + r \tag{32}$$

Substituting these equilibrium prices back into the firms' profit function gives: $\pi_1^{NT} = \frac{1}{9}(-3a + c - 2\lambda)^2$, $\pi_2^{NT} = \frac{1}{9}(3a + c + \lambda)^2$, $\pi_1^{TT} = (a + \lambda)(a + \lambda + 2r) + L$ and $\pi_2^{TT} = (a + \lambda)^2 - L$. The licensing fee that makes firm 2 indifferent between accepting and rejecting the offer is given by $L_1^{**} = (a + \lambda)^2 - \frac{1}{9}(3a + c + \lambda)^2$. Finally substituting p_1^{TT}, p_2^{TT} and L_1^{**} into firm 1's profit and maximising with respect to r yields the optimal royalty given by $r^{**} = 0$.

A.2 With a carbon tariff

We consider the following game structure: In stage 1, Firm 1 offers Firm 2 a take-it-or-leave-it fixed fee licensing contract. Firm 2 then decides whether to accept or reject the contract offered. If the offer is accepted, both firms produce clean goods, environmental damage is nullified, and the game proceeds directly to stage 3. If Firm 2 rejects the offer, we move to stage 2. Stage 2 introduces a per-unit carbon tariff t imposed on Firm 2's exports of carbon-intensive goods. This tariff is set by an independent authority in the northern developed country, whose aim is to determine the optimal rate that minimizes environmental harm from dirty imports. In stage 3, regardless of the path taken, both firms compete in the northern market as Bertrand duopolists. Based on the demand functions (given by equation (22) and (23) in section 5.1), the respective profit maximisation problems faced by firm 1 and 2 in stage 2, assuming firm 2 declines the offer are as follows:

$$\underset{p_1}{max}\ \pi_1^{NT} = (p_1 - c)q_1 = (p_1 - c)(a + \lambda - p_1 + p_2) \tag{33}$$

$$\underset{p_2}{max}\ \pi_2^{NT} = (p_2 - t)q_2 = (p_2)(a + p_1 - p_2) \tag{34}$$

We obtained the following optimal Nash-Bertrand prices of good 1 and good 2 as a function of λ and t:

$$p_1 = \frac{1}{3}(3a + 2c + 2\lambda + t) \tag{35}$$

$$p_2 = \frac{1}{3}(3a + c + \lambda + 2t) \tag{36}$$

At stage 2, The welfare maximization function is given by equation (17) on page no. 15. The optimal carbon tariff that maximizes government welfare is given by $t_b^* = \frac{(2\alpha+3)(3a+c+\lambda)}{2(\alpha+3)}$. The subscript 'b' denote bertrand competition case. The prohibitive tariff given by $t_{bp} = 3a + \lambda + c$. At Stage 3, assuming firm 2 accepts the licensing offer , the respective profit maximization problems faced by firm 1 and firm 2 are the same as in A.1 stage 2. Letting L_2^{**} denote the licensing fee that makes firm 2 indifferent between adopting and not adopting green technology, we have $L_2^{**} = (a+\lambda)^2 - \frac{(3a+c+\lambda)^2}{4(\alpha+3)^2}$ and $r^{**} = 0$.