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An Economic Analysis of the Packaging Waste Recovery Note System in the UK

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Abstract

In order to cope with the increasing scarcity of final dump sites for household wastes, the UK recently introduced an environmental policy targeted at the firms that produce and sell products that generate packaging wastes. This policy requires such businesses to hold predetermined numbers of tradable credits called "Packaging waste Recovery Notes" (PRNs). This article provides insights into the economic implications of such a policy through a simple analytical model of a recyclable product and the PRN markets. Our analysis yield two particularly interesting results. First, an increase in the required recycling rate dampens the output and landfill waste levels, while the effect on the level of recycling activities is ambiguous. Second, an increase in the landfill tax always leads to an increase in the landfill waste. We also discuss how the socially optimal landfill tax in the presence of the PRN market should be chosen.

Keywords: PRNs, Recycling, Landfill Tax, Comparative Statics.

JEL classification: Q28

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1 Introduction

Among the EU member states, there has been a major push toward diverting wastes away from landfills and promoting recycling as the concern over the shortage of landfill space has been mounting for a while. Since the 1990s, the UK, whose waste management heavily depended on landfills that absorbed over 80 percent of its waste (OECD, 1999), has introduced several policy measures to reduce and recycle wastes. Among them is the approval of tradable credits, called “Packaging waste Recovery Notes” (PRNs), to meet individually-specified recycling obligation for firms that produce and sell products that generate packaging wastes. The PRNs are issued by accredited reprocessors according to the amount of waste actually recycled, and traded among regulated firms and recyclers in an open market.

In this paper, we construct a simple analytical model of a product market and the PRN market so as to gain insights into this new policy instrument. Particularly, we conduct a series of comparative statics analysis to examine, first, how an increase in a target recycling rate affects the equilibrium recycling and landfill waste levels. Another policy effect we explore is that of an increase in the landfill tax, which is simultaneously implemented in the UK. There are two notable results from our comparative statics analysis. First, an increase in the required recycling rate dampens the output and landfill waste levels, while the effect on the recycling activity is ambiguous, partly due to the existence of the PRN market. Second, an increase in the landfill tax (or the the price of recycled material) actually raises the amount of landfill waste. In particular, as it becomes increasingly difficult to raise the recycling rate further, a constant rise in the landfill tax can start exacerbating the shortage of landfill sites. This result at least casts some doubt on the effectiveness of implementing the PRN scheme and landfill tax concurrently, as is recently practiced in the UK.

After describing the PRN scheme and other relevant policy environment in the UK in the next section, we present the structure of our model in section 3. In section 4, we conduct a series of comparative statics analysis in order to examine how the equilibrium outcomes react to marginal changes in respective policy instruments. In section 5, we briefly discuss how the socially optimal level of the landfill tax needs to be adjusted to a change in the social cost of landfill waste.

2 Background Information

Waste management of the UK has been largely driven by the EU Directives' objectives and targets. In 1994, the EU council issued the Directive 94/62/EC that required member states to pass legislation at the national level to reduce packaging waste. Since 1997, the Producer Responsibility Obligations (Packaging Waste) Regulations (PWRegs) has regulated businesses with an annual handling of more than 50 tonnes of packaging or annual turnover of more than £2 million. This covers close to 90 percent of all packaging handled by UK businesses (Department for Environment, Food, and Rural Affairs (Defra), 2006a).

In large, there are three types of agents regulated under the PWRegs: output producers and retailers, reprocessors/recyclers, and "compliance schemes". Compliance schemes act as middlemen between the first two types of agents, and guarantee to output producers and retailers that required amounts of recycling of packaging materials have been achieved by contracted reprocessors.[1] The PWRegs specifies the materials covered, distribution of recycling obligations across business categories, and calculation rules to derive their required amounts of recycling based on the scale of their business activities.[2]

The novelty of this regulation is the introduction of tradable credits to meet recycling obligation, called Packaging waste Recovery Notes (PRNs). PRNs are issued by accredited reprocessors according to the amount of waste actually recycled, and are the standardized form of evidence of recycling of packaging waste under the PWRegs.[3] At the end of each regulatory period, each output producer must hold enough PRNs for each of the six regulated materials used for packaging (glass, paper/board, aluminum, steel, plastic, and wood) to comply with the recycling requirements (1 unit of PRN corresponds to 1 tonne of a material recycled).

[1] Thus, compliance schemes essentially serve the same functions as Producer Responsibility Organizations in other European nations (Walls, 2006).

[2] For details, see Salmon (2002), Walls (2006), and Defra (2006a).

[3] Another form of standardized evidence of recycling under the PWRegs is Packaging waste Export Recovery Notes (PERNs) issued by accredited exporters of packaging materials. In our analysis, we do not make a distinction between PRNs and PERNs for simplicity.

The initial issue of PRNs are usually based on long-term contracts between compliance schemes and reprocessors. PRNs can also be traded in the open market called the Environment Exchange (a.k.a. t2e) to fill the gap between the secured holdings and the required amounts given the actual amount of packaging handled.[4] Since its launching, the volume of annual PRN trading increased from less than 100,000 tonnes in 1998 to over one million tonnes in 2009 (Table 1).[5] In terms of a percentage of the total packaging wastes recycled, the volume of trade in this secondary market grew from less than 1 percent in 1998 to over 8 percent in 2004, and more recently 12.5 percent in 2009.[6]

The achievement of packaging waste recycling effort of the UK in recent years is quite remarkable. The UK has moved well beyond the 30% recycling rate in late 1990s to meet the EU Directive's recycling targets (Defra, 2009). The recycling rate is currently just above 60%. Among the EU nations, the UK recently ranks towards the middle of the rankings of the amount of packaging used per person and the packaging recycling rate (ACP, 2008).

Besides the targets set by the (revised) EU Waste Framework Directive (2008/98/EC), the UK now must also meet the targets given by The EU Council Directive on the landfill waste (1999/31/EC). The overall aim of this so-called Landfill Directive is to reduce negative externalities from the landfill waste as much as possible (Defra, 2003). In response, the UK introduced the Landfill Tax under the Finance Act of 1996. The Landfill Tax applies to all waste that goes to licensed landfill sites, and the tax level has been raised steadily since its introduction to the level of £48 per tonne in 2010. As we can see in Table 1, an automatic annual increase has been built into this tax system, and its level is expected to reach as high as £80 per tonne by 2014.

The UK government has declared that "[b]y 2050 we hope to have achieved zero waste" (Defra, 2009). They propose that the UK should join the EU's highest-achieving

[4] Unlike the SO_2 allowance market under the US Acid Rain Program, participation in the PRN market is limited to the regulated parties. Another notable difference from the SO_2 allowances is that PRNs are not "allowances" in the sense that they do not represent emission rights. Rather, they are "credits" in that they represent fulfilled abatement obligations.

[5] Since 2004, PRNs and PERNs are traded in both the spot and forwards markets. The latter has reached almost 40 per cent of the total trading volume in 2009, reflecting participants' preferences to lock in prices as well as the maturity of the market.

[6] These rates are derived by the authors using the information on the amount of total packaging waste recycled in 1998, 2004, and 2008, from Defra (2006b and 2010b).

Table 1: Landfill Tax of the UK

Year	tax per tonne
1996	£7
1999	£10, rising annual by £1 till 2004
:	
:	
2004	£15, rising annually by £3 from 2005
:	
2007	£24, rising annually by £8 from 2008
:	
2010	£48
:	
2014	£80

Sources: Barrow (2003); Defra (2010a).

member states by pushing its recycling target rate to 71.9 percent by year 2020 (Defra, 2010a).

In the past fifteen years, the total amount of landfilled packaging wastes has decreased gradually, but not at such a rapid pace as is directly estimated by the constant increase in the recycling rate (Defra, 2011). This can be attributed to a rather significant increase in the packaging waste flow in the UK during the same period. Defra (2011) shows that total packaging in waste stream had risen from around 9 million tonnes per year in the late 90's to just below 11 million tonnes towards the end of the first decade of the new century. This implies that the issue of diminishing landfill sites has not been fully solved by these policy measures and ensuing changes in the behaviors of the concerned parties. We attempt to provide a possible explanation for this problem in the following analysis.

3 The Model

In our model there are three important agents, i.e., a consumption good producer, a consumer and a recycler, and we assume that they all behave as price-takers.[7] For the

[7] Although the development of the secondary market described in the previous section is an interesting topic, we ignore the roles of this market in our model. This omission would be innocuous in our context

sake of simplicity, we consider only one household, one recycler and one output producer in our model as this would not lead to any loss of generality under our setting in obtaining the qualitative results that follow. We only deal with one type of material and do not explicitly model the workings of the input markets.

3.1 The Behavior of an Output Producer

An output producer's objective is to maximize its profit by selling a product, x. Its production requires two distinct types of essential inputs. On one hand, it requires a packaging material denoted by z. On the other hand, all the other necessary inputs to produce this product are aggregated into a composite input, y. The production function is described by the following Leontieff type:

$$x_S = \min\left\{\frac{z}{\delta}, g(y)\right\}, \tag{1}$$

where x_S denotes the supply of x and the parameter δ represents the physical amount of the packaging material required for producing one unit of output.[8] We suppose that the function $g(y)$ has the following properties: $g' > 0$ and $g'' < 0$. The total cost of production is given by $P_z z + P_y y$, where P_z and P_y are respectively the prices of the two inputs, z and y.[9] Since the cost-minimizing firm would choose $x_S = \frac{z}{\delta} = g(y)$, we have $z = \delta x_S$ and $y = g^{-1}(x_S)$. For notational simplicity, we redefine $f(x_S) \equiv g^{-1}(x_S)$ with $f' > 0$ and $f'' > 0$, given the properties of $g(y)$ just above. Thus, we have $y = f(x_S)$ for a cost-minimizing firm.

In addition to the production cost, the firm incurs a payment for obtaining the required PRNs. The PRN scheme is introduced here in the following way. As the packaging input, z, is the source of waste after the consumption of the output, the amount of the PRNs that the firm must hold to meet its legal obligation is set proportionally to z by the legislation. We denote this proportion by $\alpha(0 < \alpha < 1)$. The firm must purchase the

where there is no heterogeneity within respective agents and no uncertainty is considered.

[8] Hence, technological development of less packaging implies a decrease in δ. Although we do not deal with the evolution of δ in this paper, it would be an important issue that we would like to explore in future studies especially when the analytical framework has been gradually developed by such works as Fullerton and Wu (1998) and Calcott and Walls (2000).

[9] We assume that P_z and P_y are sufficiently low so as to obtain an interior solution in the output market.

quantity αz of PRNs at the price of P_n per unit. This price of a PRN is determined endogenously in the PRN market as we describe below.

The profit maximization problem of a representative output-producing firm can be expressed as:

$$\underset{x_S,\ z,\ y}{Max}\ \Pi^x = P_x x_S - (P_z z + P_y y) - P_n \alpha z. \tag{2}$$

Incorporating the considerations above, (2) can be rewritten as:

$$\underset{x_S}{Max}\ \Pi^x = P_x x_S - (P_z \delta x_S + P_y f(x_s)) - P_n \alpha \delta x_S. \tag{3}$$

The first-order condition for this problem is given by:[10]

$$P_x - P_z \delta - P_y f'(x_S) - P_n \alpha \delta = 0, \tag{4}$$

where P_x is the marginal revenue, and the other terms, in total, represent the marginal cost of production.

3.2 The Behavior of a Household

As each unit of the product contains δ units of the packaging material, household consumption of x units of the product results in δx units of packaging waste to be disposed of. Each household uses collection services specifically designed for subsequent recycling of the waste. We suppose that the collectors of the recyclable waste are municipal governments which then provide recyclers with the recyclable waste free of charge.[11] Note that the household does not receive any monetary payment from the recycler. Also, we ignore the physical costs of handling the recyclable waste properly as well as the opportunity costs of those activities by the household.

With the use of a quasi-linear utility function, we consider that a representative household's behavior is approximated by the following constrained utility maximization problem with respect to the product demanded, x_D, and a numeraire, m:

$$\underset{x_D,\ m}{Max}\ U = u(x_D) + m, \tag{5}$$

[10] As can be easily confirmed, second-order conditions throughout the paper are all satistied.

[11] Municipal collection service of general and recyclable garbage is quite prevalent in developed nations (Walls, Macauley and Anderson, 2005).

$$s.t.\ \ P_x x_D + m \leq I, \tag{6}$$

where I is the household's total income, and $u(x_D)$ signifies the utility arising from consuming x_D with the following properties: $u' > 0$ and $u'' < 0$.

The first-order condition for the household's utility maximization problem is given by:

$$u'(x_D) - P_x = 0. \tag{7}$$

3.3 The Behavior of a Recycler

A recycler can process one unit of the recyclable waste it freely obtains, to create one unit of a recycled material which can be sold at the exogenous price of P_r. We consider that, if the government provides a recycling subsidy, it simply boosts P_r. Under the PRN scheme, moreover, a recycler can sell the notes generated by recycling to an output producer at the price of P_n, which is endogenously determined by the market clearing condition in the PRN market. Hence, the marginal revenue a recycler obtains by recycling one unit of waste is $P_n + P_r$. Meanwhile, the recycling activity imposes physical costs on a recycler in sorting and processing the waste. The recycler's cost function is assumed to be $c(r)$ with the properties: $c' > 0$ and $c'' > 0$. The recycler also has to dispose of the remaining waste at a dump site, by paying the unit cost of P_l, a landfill tax.[12] We consider that local governments are in charge of managing landfill sites, and this landfill tax is received by the government to cover its operating cost. With a sufficiently high marginal cost of recycling, a recycler will adopt this disposal option to a certain extent.

The profit-maximization problem of a recycler is:

$$\underset{r}{Max}\ \Pi^r = (P_n + P_r)r - P_l(z - r) - c(r). \tag{8}$$

The first-order condition is:

$$P_n + P_r + P_l - c'(r) = 0, \tag{9}$$

where the first three terms represent the marginal revenue of recycling, including the avoided landfill tax, and $c'(r)$ is the marginal cost of recycling.

[12] We assume that P_l, as well as P_r, is sufficiently low in relation to the cost of recycling so as to obtain an interior solution in the PRN market. Thus, the PRN price, P_n, is always positive in the equilibrium.

3.4 Market Equilibrium

Finally, as both the product and PRN markets need to clear at the equilibrium, we have the following two conditions:

$$x_D = x_S, \tag{10}$$

$$r = \alpha z, \tag{11}$$

where (10) is for the output market and (11) is for the PRN market.[13] The market equilibrium for the model is described by (4), (7), (9), (10) and (11).

4 Comparative Statics Analysis

In this section, we conduct a series of comparative statics analysis with respect to three possible policy instruments. The policy variables we mainly focus on here are α, which signifies the stringency of the recycling obligation, and P_l, a landfill tax per unit of waste. Also, we briefly discuss the subsidy for recycling activities, which raises the price of the recycled material, P_r.

Invoking $z = \delta x$, the equilibrium conditions for the base model can be written as:

$$P_x^* - P_z\delta - P_y f'(x^*) - P_n^*\alpha\delta = 0, \tag{12}$$

$$u'(x^*) - P_x^* = 0, \tag{13}$$

$$P_n^* + P_r + P_l - c'(\alpha\delta x^*) = 0, \tag{14}$$

where P_x^*, x^*, and P_n^* respectively denote the equilibrium values of the output price, the output level, and the price of PRN.

The so-called comparative statics equations and its direct results are in the Appendix. Based on those results, we can obtain several propositions on the equilibrium amount of landfill waste.

Proposition 1. *An increase in the recycling rate always leads to a reduction in landfill*

[13] At the equilibrium, we cannot have $r < \alpha z$ as this would violate the PRN regulation. Also we rule out the case where $r > \alpha z$ as this implies that the price of a PRN becomes zero and the producer would be able to obtain whatever amounts of PRNs freely.

waste.

Proof. Since the equilibrium recycling level is given by $r^* = \alpha z^*$, the amount of landfill waste is: $z^* - r^* = (1-\alpha)z^* = (1-\alpha)\delta x^*$. Therefore, we have:

$$\frac{\partial(z^* - r^*)}{\partial \alpha} = -\delta x^* + (1-\alpha)\delta \frac{\partial x^*}{\partial \alpha}. \tag{15}$$

(A2) confirms that the sign of the R.H.S. of (15) is negative. **Q.E.D.**

Proposition 1 suggests that raising the statutory recycling rate always reduces the landfill waste successfully as an increase in α holds down the output level and the ratio of recycling to the total output is raised at the same time. However, its impact on the level of recycling activities is not always positive as is confirmed by:

$$\frac{\partial r^*}{\partial \alpha} = \delta x^* + \alpha\delta \frac{\partial x^*}{\partial \alpha}, \tag{16}$$

whose sign is ambiguous given (A2). This implies that there might be a trade-off between encouraging recycling activities and reducing the landfill waste through the adjustment of the mandatory recycling rate in the PRN system. This can pose a problem if the recycled material commands a significant economic value. As α does not affects the supply of the recycled material as seen in (9), the equilibrium levels of r are driven solely by the demand for the PRNs.

The following would be the most important result of our analysis:

Proposition 2. *An increase in the landfill tax always increases the amount of landfill waste.*

Proof. Again using the definition of landfill waste, we have $z^* - r^* = (1-\alpha)\delta x^*$. Thus:

$$\frac{\partial(z^* - r^*)}{\partial P_l} = (1-\alpha)\delta \frac{\partial x^*}{\partial P_l}. \tag{17}$$

(A5) shows that the sign of the R.H.S. of the above equation is positive. **Q.E.D.**

Intuitively, this proposition can be explained in the following way. An increase in P_l raises the benefit of recycling to a recycler and consequently lowers the cost of production via a lower P_n^*, as is confirmed by (A7). Thus, the production level rises, as well as the use of the packaging material input, z. In our framework, this increase in the waste flow necessarily overwhelms the increase in the recycling effort to yield a greater amount of landfill waste. Proposition 2 is in contrast with a simple assertion that an increase in the cost of an activity will discourage such an activity. The nature of the PRN market gives rise to this result.[14]

Finally, we consider the impact of an increase in the price of recycled material, P_r, upon the amount of landfill waste. This increase might be due to either an increase in the subsidy for recycling activities or a hike in the demand for the recycled material. Here, we have:

Proposition 3. *An increase in the price of the recycled material always raises the amount of landfill waste.*

Proof. Once again, we have $z^* - r^* = (1-\alpha)\delta x^*$ for the equilibrium amount of landfill waste. Thus,

$$\frac{\partial(z^* - r^*)}{\partial P_r} = (1-\alpha)\delta\frac{\partial x^*}{\partial P_r}. \tag{18}$$

Then, (A8) confirms that its sign is positive. **Q.E.D.**

As we can easily see from (14), an increase in the landfill tax and an increase in the price of the recycled material work in the exact same way. Besides the subsidy from the government, the latter change can be caused by the functioning of the recycled material market, which is not explicitly modeled in this paper. When the recycled material is valued more highly there, the amount of landfill waste rises, which aggravates the landfill shortage.

[14] It is also important that a consumer is not responsible for collection charge or any other costs in our model. Our setup would be more plausible when there is strong concern for illegal disposal of waste by a household, as is often the case with packaging materials.

5 Optimal Landfill Tax under the PRN System

In order to gain further insights into the working of the landfill tax under the PRN system, we specifies the three functions above as follows: $g(y) = y^{\frac{1}{2}}$, $u(x_D) = ax_D - \frac{1}{2}bx_D^2$, and $c(r) = \frac{1}{2}cr^2$. As our focus in this section is the desirable level of the landfill tax from a social welfare perspective, we introduce the following two costs. The first is the social cost of disposing of waste at landfill sites, including negative externalities at those sites. We assume that this marginal social cost is constant at which θ. The second is associated with the transportation of the household waste by the municipal government, whose marginal cost is given by η. Then, we can define the social welfare, W, as follows:

$$W = \Pi^x + U + \Pi^r - \theta(1-\alpha)\delta x - \eta\delta x + P_l(1-\alpha)\delta x, \tag{19}$$

where the last term is the tax revenue received by the municipal government. Given the specific functional forms above and (3), (5), (6) and (8) in section 3, the value of the social welfare at the equilibrium, denoted by W^*, is, after summarizing:

$$W^* = -(P_y + \frac{1}{2}b + \frac{1}{2}c\alpha^2\delta^2)x^{*2} + \{a - P_z\delta + P_r\alpha\delta - \theta(1-\alpha)\delta - \eta\delta\}x^* + I. \tag{20}$$

Here, we consider that the mandatory recycling rate, α, is exogenously given as a directive from the EU, for instance, and discuss how the social planner should choose the landfill tax, P_l, to maximize W^*.

The first-order condition of the maximization of W^* with respect to P_l is:

$$\frac{\partial W^*}{\partial P_l} = -(2P_y + b + c\alpha^2\delta^2)x^*\frac{\partial x^*}{\partial P_l} + \{a - P_z\delta + P_r\alpha\delta - \theta(1-\alpha)\delta - \eta\delta\}\frac{\partial x^*}{\partial P_l} = 0, \tag{21}$$

and, eliminating $\frac{\partial x^*}{\partial P_l}$, we get an equality:

$$F \equiv -(2P_y + b + c\alpha^2\delta^2)x^* + a - P_z\delta + P_r\alpha\delta - \theta(1-\alpha)\delta - \eta\delta = 0. \tag{22}$$

This equality implicitly determines the relationships between the socially optimal landfill tax, P_l^*, and respective exogenous variables.

Then, we can insert the specific functions above into (12), (13) and (14) to obtain the equilibrium values of all the endogenous variables. Especially, for the sake of manipulating

(22), we derive:

$$x^* = \frac{-P_z\delta + \alpha\delta(P_r + P_l) + a}{2P_y + c\alpha^2\delta^2 + b}, \tag{23}$$

and

$$\frac{\partial x^*}{\partial P_l} = \frac{\alpha\delta}{2P_y + c\alpha^2\delta^2 + b}. \tag{24}$$

Let us now consider how P_l^* needs to change in response to an increase in the social cost of landfill waste. Given (22), denoting the optimal value of P_l by P_l^* and totally differentiating the equation with respect to P_l^* and θ yield:

$$\frac{\partial P_l^*}{\partial \theta} = -\frac{\frac{\partial F}{\partial \theta}}{\frac{\partial F}{\partial P_l{}^*}} = \frac{\alpha - 1}{\alpha} < 0. \tag{25}$$

From (25), we can immediately obtain the following proposition:

Proposition 4. *When the social cost of landfill waste increases, the optimal landfill tax decreases.*

This proposition implies that, when the social cost of landfill waste is increasing, the level of the landfill tax should be decreasing. Indeed, the sign of $\frac{\partial P_l^*}{\partial \theta}$ is predictable from Proposition 2 above: as the social cost of landfill waste increases, the landfill tax must be lowered to reduce the amount of landfill waste. If the further accumulation of the waste leads to an increase in the marginal social cost of the landfill over time, the optimal level of landfill tax needs to decrease accordingly.

6 Concluding Remarks

In light of the recent policy trend in the UK, our comparative statics analysis focuses on the effects of an increase in the required recycling rate and an increase in the landfill tax on equilibrium outcomes. Our results show that requiring a higher recycling rate reduces landfill waste while this can negatively affect the overall recycling level. Our analytical result also indicates that a higher landfill tax actually increases the amount of landfill waste, which raises a suspicion that the continuous increase in the landfil tax level, as we are witnessing in the UK, might be offsetting the favorable effect of the PRN scheme in terms of reducing the landfill waste. At least, we need to be aware of the fact that these two policy measures are not necessarily complementary for this particular objective.

Admittedly, there are several interesting features in the packaging waste recycling system in the UK that we must leave out of this paper for simplicity. These include the development of the secondary PRN market and the PERN market, and the possibility of a strong market power possessed by some compliance schemes in the PRN market. Especially the latter consideration would directly affects the results of our analysis. Although the effects of such a market distortion seem rather insignificant so far (Salmons, 2002), this particular concern is often raised against the Producer Responsibility Organization in Germany (Lehmann, 2004, and Fleckinger and Glachant, 2010) and it would be worthwhile to explore the effects of non-competitive market structures in a future study.

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Appendix: Comparative Statics Results

Based on the system of equations, (12), (13), and (14), we can obtain the so-called comparative statics equation for the base model as follows:

$$\begin{bmatrix} -P_y f''(x^*) & 1 & -\alpha\delta \\ u''(x^*) & -1 & 0 \\ -c''(\alpha\delta x^*)\alpha\delta & 0 & 1 \end{bmatrix} \begin{bmatrix} dx^* \\ dP_x^* \\ dP_n^* \end{bmatrix} = \begin{bmatrix} P_n^* \delta d\alpha \\ 0 \\ c''(\alpha\delta x^*)\delta x^* d\alpha - dP_l - dP_r \end{bmatrix},$$

where the determinant of the Jacobian matrix, J, can be found as:

$$\left|J\right| = P_y f''(x^*) + c''(\alpha\delta x^*)\alpha^2\delta^2 - u''(x^*) > 0. \tag{A1}$$

Given (A1) and the assumptions on the household's utility and firm's production functions described in the text, we can obtain the following comparative statics results with respect to the three different types of economic instruments:

$$\frac{\partial x^*}{\partial \alpha} = \frac{-P_n^*\delta - c''(\alpha\delta x^*)\alpha\delta^2 x^*}{\left|J\right|} < 0, \tag{A2}$$

$$\frac{\partial P_x^*}{\partial \alpha} = \frac{-u''(x^*)c''(\alpha\delta x^*)\alpha\delta^2 x^* - u''(x^*)P_n^*\delta}{\left|J\right|} > 0, \tag{A3}$$

$$\frac{\partial P_n^*}{\partial \alpha} = \frac{P_y f''(x^*)c''(\alpha\delta x^*)\delta x^* - P_n^*\delta c''(\alpha\delta x^*)\alpha\delta^2 - u''(x^*)c''(\alpha\delta x^*)\delta x^*}{\left|J\right|}, \tag{A4}$$

$$\frac{\partial x^*}{\partial P_l} = \frac{\alpha\delta}{\left|J\right|} > 0, \tag{A5}$$

$$\frac{\partial P_x^*}{\partial P_l} = \frac{\alpha\delta u''(x^*)}{\left|J\right|} < 0, \tag{A6}$$

$$\frac{\partial P_n^*}{\partial P_l} = \frac{-P_y f''(x^*) + u''(x^*)}{\left|J\right|} < 0, \tag{A7}$$

$$\frac{\partial x^*}{\partial P_r} = \frac{\alpha\delta}{\left|J\right|} > 0, \tag{A8}$$

$$\frac{\partial P_x^*}{\partial P_r} = \frac{\alpha\delta u''(x^*)}{\left|J\right|} < 0, \tag{A9}$$

$$\frac{\partial P_n^*}{\partial P_r} = \frac{-P_y f''(x^*) + u''(x^*)}{\left|J\right|} < 0. \tag{A10}$$