Ecological Economics 129 (2016) 172–181

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Gains of integrating sector-wise pollution regulation: The case of nitrogen in Danish crop production and aquaculture

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ARTICLE INFO

Article history:
Received 6 January 2016
Received in revised form 19 May 2016
Accepted 23 May 2016
Available online 23 June 2016

JEL Classification:
C68
Q25
Q28
Q52

Keywords:
Computable General Equilibrium model
Externality market
Nitrogen regulation
Sector economic costs
Agriculture
Aquaculture

ABSTRACT

This paper extends the Orani-G Computable General Equilibrium model with an externality market. The externality market is modelled with a limited number of pollution permits that are traded between representative firms in different sectors. The model is applied to identify the gains of a common nitrogen regulation system for Danish agriculture crop and aquaculture production. Common regulation across the two sectors is found to increase GDP by euro 32 million, corresponding to 2.2% of their initial GDP contribution. The direct effect in the two sectors is euro 39 million, where the spill-over effect is −7 million. Full use of recirculation technology in aquaculture entails a further increase in GDP to 106 million. The introduction of a common regulatory system and recirculation technology, simultaneous with a reduction of the common nitrogen cap of 17.6%, corresponding to the current policy objectives, is found to increase GDP by 52 million, 4.1% of their initial contribution. Hence, introducing a common regulatory system and taking advantage of the new technology more than counterbalances the negative socio-economic effect of a cap reduction. The analysis points to the importance of introducing more coherent regulatory frameworks that include all polluters under the same regulatory system.

1. Introduction

When introducing environmental regulation to reduce pollution, low-hanging fruits — from which a fast and secure effect can be achieved immediately — are often the first to be targeted. Further down the road, other polluters are included in the regulatory framework to cover all contributions to the externality problem. However, this often results in an incoherent regulatory framework even though it targets the same externality.

A good example of this is the regulation of nutrient emission into waterbodies in Denmark. In this case, the low-hanging fruits were point-source polluters, such as, industries, households and land-based aquaculture production, where the handling of the more difficult, diffuse sources of pollution — such as agriculture — were included and further evolved in the regulatory framework over a longer period of time. The piece-by-piece implementation of the regulation has resulted in an incoherent regulatory framework with different rules and regulations applying to different sectors even though that the regulation is targeting the same externality.

The reason why nitrogen has become a problem in many developed countries is an intensification of the agriculture production and increasing use of fertilizers (Boesch, 2008). In Denmark, the agriculture sector contributes more than 70% of the nitrogen surplus to the water environment (Dubgaard et al., 2009). The main problem with the discharge is that the nutrients end up in the estuarine water environment, such as fjords and the shallow coastal waters (Boesch, 2008; Selman et al., 2008). The transferred nutrients can threaten coastal ecosystems, causing oxygen depletion, algae blooms, and hypoxia.

Strict environmental regulation of the use of nitrogen is considered to be the most important barrier to growth in the Danish aquaculture sector (Nielsen, 2011, 2012; Nielsen et al., 2014). Furthermore, nitrogen use in crop production is assessed as being 14–16% below its optimal level (Dalgaard et al., 2014), indicating that agriculture crop production is also restrained by tight regulation. The issue of improved allocation of nitrogen between sectors, which is made possible by more efficient regulation, is therefore important as it may lead to gains for the Danish society.

The purpose of this paper is to identify the gains of a common regulatory system of nitrogen emission, allowing for an optimal allocation between Danish agriculture crop and aquaculture production sectors. An extended version of the Orani-G Computable General Equilibrium (CGE) model of Horridge (2003) is applied that includes a nitrogen externality market. It is found that the implementation of one common

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http://dx.doi.org/10.1016/j.ecolecon.2016.05.009
0921-8009/

regulation system will increase the overall GDP contribution from the two sectors, in which aquaculture will grow substantially and agriculture crop production will experience a minor reduction. Even in a scenario where the nitrogen cap is reduced by 17.6%, in accordance with the policy objectives of the Water Environment Action Plan, the gains of a common regulatory system outweigh the loss of the reduced cap.

Gains from a common nitrogen quota system are believed to stem from the fact that point source and non-point source nitrogen polluters are regulated separately in Denmark. Agriculture crop production is restricted by an input limitation on fertilizer use, which is equal per hectare across the country. Aquaculture is limited in terms of input of feed. Readjusting the regulation from focusing on input to the actual undesired output will allow for more transparency, which will lead to a more optimal allocation of the undesired output — nitrogen emissions — adding to the gain of a common regulation. Furthermore, adjustment to separate regional caps may lead to a gain. The transferability of emission permits also induces gains when more efficient producers buy nitrogen from less efficient producers, although it is only identified in this article between sectors, not between individual companies. Taxes have the same effect when set at the same level as the optimal price of the permit. A common regulation for agriculture crop production and aquaculture adds to these gains by removing barriers between sectors by allowing the most efficient sector to survive and grow.

When optimal use of the environmental resources is an aim of the regulation of environmental externalities, all polluters must be included in a coherent regulatory framework. Hence, the optimal level of emissions is found where the total marginal benefit equals the sum of the total marginal cost (including the externality), which will induce welfare gains, either in terms of an improved environment if the existing cap is set too high or increased production if the cap is set too low.

The effects of nitrogen policy reforms on the entire economy have been studied in CGE models and applied to identify the negative effects on stricter regulation. Brouwer et al. (2008) identifies the impacts on the Net National Income of reducing emission levels of nutrients and improve water quality in the Netherlands. Dellink et al. (2011) use a dynamic applied general equilibrium model to evaluate the effect of a derogated water policy in the European Water Framework Directive and find that indirect costs are at least as high as the direct costs.

Gains of improved nitrogen regulation efficiency, as opposed to stricter policies, have not been widely studied to the knowledge of the authors, although Jensen et al. (2013) studied whether the cost of meeting the stricter policy objectives of nutrient emission reduction of the Water Framework Directive in the 23 river basins in Denmark are disproportionate compared to benefits. It is found that the costs are disproportionate to the benefits in some river basins and proportionate in others. This implies that nutrient pollution is above the optimal pollution level in some cases and below the optimal level in others. This paper identifies the direct gains and spill-over effects of integrating sector-wise nitrogen regulation. Both types of effects are found to be important.

The paper is organized as follows. In section two, the model of optimal reallocation of pollution permits between representative firms in different sectors is developed. In section three, nitrogen regulation in the Danish case is described, and in section four, the CGE model is operationalized. The fifth and sixth sections present the data and results, and section seven concludes the paper.

2. Model of Optimal Reallocation of Pollution Permits

The gains of integrating sector-wise pollution regulation into one common regulation system are identified as increased contribution to GDP, which moves between polluting and other sectors. Increases in GDP contribution appears when sector-wise regulation is replaced by common regulation that allows the reallocation of pollution permits to the sectors that generate the largest profit. The marginal profit of polluting an extra unit corresponds to the shadow price that measures 'the extra profit a sector can achieve if it is allowed to use one more pollution permit, which is the limiting factor for increasing production'. The shadow price reveals the value of the scarce input — pollution permits — for which a market initially does not exist.

With sector-wise regulation, the shadow prices differ between sectors. If common regulation is introduced, the optimal level of nitrogen reallocation, given a cap, is achieved where the marginal profit of using one extra pollution permit is equal across all sectors. The optimal level of reallocation for nitrogen pollution permits between two sectors, aquaculture and crop production, is identified, taking into account spill-over effects to other sectors using a CGE model. This level is compared to the current level. An overview of the model is presented in Fig. 1 for two sectors, A and B; *e* is the number of permits; *pp.* is the permit price; *D* and *S* are the demand and supply of permits, respectively; *Mπ* is the marginal profit; and *0* and *1* refer to the initial situation with separate regulation, respectively to the situation with optimal reallocation of permits following common regulation. Assuming that the entire profit of production is capitalized in the permit price, the demand for permits equals the marginal profit of production, as measured by the shadow price. In the figure, the permit demand curves decrease with the number of pollution permits because permits are only one of several input factors that induce a decreasing marginal profit even under the constant returns-to-scale assumption and because the price elasticities of demand are negative.

In the initial situation, both the right and left panel represent a situation where permit demand and supply is equal in each separate sector without connection. Introducing a common regulation system leads to reallocation of permits because $pp_B^0 > pp_A^0$. The optimal level of reallocation appears where the marginal profit in all sectors are equal, i.e., where $pp^1 = pp_A^1 = pp_B^1$, given an unchanged cap where $e_A^0 + e_B^0 = e_A^1 + e_B^1$. Because the permit demand curves also measure marginal profit, the integer represents absolute profit, and the finite integer between e^0 and e^1 in each sector measures the change in profit from the current situation to the optimal reallocation level. With the cap given, the permits are sold from the representative firm in one sector and bought by the representative firm in another sector, implying that the widths of the two areas (shaded and solid) are the same. Because the heights of the area in sector B are higher than in sector A, a gain is achieved until $pp_A^1 = pp_B^1$, i.e., until the optimal reallocation level is achieved.

If the cap is reduced with the introduction of a common regulation, the cap reduction induces a decrease in profit, which is measured as the finite integer between e^0 and e^1 where the common regulation induces a profit increase, as shown above. The full effect depends on the effect that dominates.

3. Nitrogen Regulation of Danish Agriculture Crop and Aquaculture Production

Denmark is a small country with a large agriculture sector that farms its land intensively. Sixty-five percent of all Danish land is cultivated. Denmark is almost surrounded by typically shallow water and is, therefore, exposed to over-fertilization, which leads to eutrophication and hypoxia that can affect wildlife considerably. Over-fertilization is the result of nutrient pollution with nitrogen and phosphorus.

In 2010, the nitrogen surplus, i.e., nitrogen that is supplied to the fields but is not removed with harvest, was 266,000 t, whereas the phosphorus surplus was 190,000 t (Vinther, 2013). The nitrogen loss to the water environment, which potentially causes damage, was 56,800 t. Crop production was the largest contributor at 70%. Aquaculture contributed 2%, and other point-sources contributed 10% (M. Nielsen et al., 2015). The remaining 18% is from nature.

In the mid-1980s, decade-long discharges of nitrogen and phosphorus led to increasing evidence of eutrophication (Carstensen et al., 2006; Conley et al., 2007), which induced the introduction of three Danish Water Environment Action Plans (implemented in 1987, 1998 and 2004) and the Nitrate Directive and Water Framework Directive from the European Commission (implemented in 1990 and 2003). These have succeeded in reducing the nitrogen and phosphorus levels