Implications of Initial Assumptions in Agri-Environmental Nitrogen Pollution Reduction Policy Design: Quasi-Empirical Evidence from Croatia

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Abstract

This paper aims to extend understanding of potential general equilibrium effects of nitrogen pollution reduction policies in multifunctional agriculture. Under the EU Nitrates Directive, to achieve agricultural nitrogen pollution reduction, a country can choose between (or combine) market and command-and-control measures. To deal with nitrate pollution from agricultural sources Croatia uses measures such as input regulations and management practices, rather than market-based measures. This paper evaluates welfare and macroeconomic effects of selected market and command-and-control based agricultural nitrogen reduction policies within Croatian data based CGE model. The paper highlights the importance of usual theoretical assumptions, i.e. labor market cleaning assumption and the degree of substitutability of nitrogen in agricultural production, for policy prescriptions. Namely, the results suggest that agri-environmental policy prescriptions largely depend upon labor market cleaning assumption and substitutability of nitrogen in agricultural production. The paper also emphasizes current limitations of CGE models for agri-environmental nitrogen reduction related policies evaluation and highlights the methodological and database development needs for future research.

Key Words

agricultural nitrogen pollution; nitrogen reduction policy design; CGE model; Croatia

1 Introduction

Research interests for excessive reactive nitrogen creation and its wide-ranging adverse effects on the environment and human health gained speed in the second half of 1990's. The timing of the rise of the popularity of these issues is not accidental. MILLENNIUM ECOSYSTEM ASSESSMENT (2005) suggests that reactive nitrogen flows in land-based ecosystems doubled during the 1960-2005 period. According to GALLOWAY et al. (2004), in the early 1990's anthropogenic human activities created 156 teragrams of reactive nitrogen per year, which is a 10-fold increase compared to the 1860's. To emphasize the importance of reactive nitrogen reduction, ERISMAN et al. (2008) point out that of all chemical elements human activity has increased the presence of nitrogen the most. Moreover, ROCKSTRÖM et al. (2009) show that nitrogen cycle already surpassed its 'planetary boundary'. Worryingly, KAHILUOTO et al. (2014) indicate that ROCKSTRÖM et al. (2009) estimates of 'planetary boundary' and current nitrogen flows are rather conservative.

Extensive review of available scientific evidence in the area, carried out by Vitousek et al. (1997), offered one of the first comprehensive indications "that human alterations of the nitrogen cycle" have serious and wide spread consequences in the long run. Literature in the area exploded at the beginning of new millennium, whereas research carried by Galloway et al. (2004), Rockström et al. (2009), Brink et al. (2011) etc. have defined a long list of excessive reactive nitrogen creation costs. According to these studies, widely accepted nitrogen emission costs list includes human health costs, costs incurred to the eco-systems, climate change costs and ozone depletion. Significant part of the rapid reactive nitrogen creation increase has been triggered by rising demand (supply) for (of) food. Galloway et al. (2004) estimates show that food production contributes to reactive nitrogen creation with 77%. Under the assumption of unchanged worldwide trends, the authors estimated that by 2050 reactive nitrogen flows around the world could increase by approximately 65%.

Despite growing researchers and policy makers interest in the field of agricultural nitrogen pollution reduction, social costs of nitrogen pollution still remain largely externalized (SCIENCE FOR ENVIRONMENT POLICY, 2013), while agricultural nitrogen reduction measures have been only partially successful (OENEMA et al., 2009). Namely, in food production sector, which is characterized by many independent and diverse actors, nitrogen pollution mitigation policies proved to have a slow response on policy incentives which is reflected by the slow progress (low efficiency of the policy incentives) in the reduction of

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different nitrogen pollution sources in the sector (OENEMA et al., 2011). This paper aims to provide an analysis of efficiency and general equilibrium effects of several nitrogen reduction policies using computable general equilibrium (CGE) model for small open economy which deals with market distortions (i.e. labor market disequilibrium) in the presence of agricultural amenities. Additionally, the paper addresses the implications of substitutability of nitrogen in agricultural production for policy prescriptions.

The main objective of this paper is to analyze the effects of selected market and command-and-control based agricultural nitrogen reduction policies in Croatia, which currently uses command-and-control measures[1] to deal with nitrate pollution from agricultural sources.

The research emphasizes the importance of initial assumptions in the analysis of agricultural nitrogen reduction policies, since policy makers deal with several theoretical assumptions violations. With this objective in mind the paper focuses on the role of available production technologies and labor market imperfections in determination of efficiency, welfare and general equilibrium effects of selected agricultural nitrogen reduction policies. According to MILLENNIUM ECOSYSTEM ASSESSMENT (2005) more suitable measures are associated with implementation difficulties, and policymakers might evaluate the trade-offs between cost-efficiency and ease of implementation. On the other hand, most of the "academic"[2] papers base their nitrogen reduction policy recommendations on large open economies and well-functioning labor markets general equilibrium models. As such, nitrogen reduction policy recommendations are suitable for economies which fit these assumptions. Besides the importance given to factors markets tax distortions, there is no available academic research which acknowledges potential importance of available production technologies and labor market imperfections. Although series of CGE models used for policy impact assessment use very sophisticated models which depict many imperfect market conditions and different production technologies, these models have not been customized and used for the analysis of nitrogen reduction policies until recently. The paper acknowledges limitations of the CGE models for evaluation of agri-environmental nitrogen reduction policies and emphasizes the methodological and database development needs for future research. Although some preliminary results for the US have been published (LIU et al., 2018), the model is still in its experimental phase.

Our results indicate that policy prescriptions largely depend upon labor market cleaning assumption and substitutability of nitrogen in agricultural production.

The paper is structured as follows. The following section summarizes studies which use similar theoretical and methodological approach in the analysis of agri-environmental policies in general – and nitrogen-reduction policies in particular. The third section describes the modeling approach, the data and methodological limitations. Forth part of the paper deals with efficiency and general equilibrium effects of evaluated nitrogen reduction measures within Croatian data based CGE model. The final section describes the main conclusions drawn from the analysis and identifies study's limitations.

2 Literature Review

Parry et al. (2012) showed that for most environmental problems a set of well-balanced fiscal policy tools (taxes or emission allowances) are the best way to include external costs in the price of a polluting good. Such measures are income source for the government and can be used for environmental investments. Still, Goulder and Parry (2008) point out that there is no single instrument clearly superior along all the dimensions relevant to the policy choice. Therefore, authors state that it is possible (even desirable) to design hybrid instruments, as many pollution problems implicate more than one market failure (which is common

[1] Most of the regulations, which deal with nitrate pollution from agricultural sources in Croatia, are specified in Law on Fertilizers and Soil Improvers and in "Ordinance on Good Agricultural Practice in the Use of Fertilizers". Croatian Action Programme specifies that the quantity of livestock manure applied in one year to land on a farm, together with the one deposited on land by livestock, cannot exceed an amount containing 170kg nitrogen per hectare (ha). It also sets limits on the application of inorganic nitrogen.

[2] Through this paper syntagma „academic papers (models)" and syntagma „practically (or policy) oriented models" are used to make the distinction between small-scale models developed to investigate particular research question (like the one developed in this paper) and sophisticated large-scale models which are often used for policy impact assessment. However, this distinction does not imply that academic papers are underdeveloped or that policymakers use more sophisticated models which are not interesting from an academic point of view. Both types of models are academic, in a sense that are published in academic journals, and both types of models are useful for their own purpose.

in agriculture). Some theoretical research and policy reports suggest that emission allowances could be superior to taxation due to lower emissions reduction uncertainty. However, the emission trading system possibilities and application is limited in agriculture due to the difficulties of tracking the nonpoint sources, particularly the water pollution generated by the agricultural sector (GOULDER, 2013).

In the analysis of efficiency and welfare as well as economic effects of environmental policies in general – and agri-environmental policies in particular – many researchers and policymakers rely on the results of partial and general equilibrium models. Within these classes of models, it is possible to distinguish two classes of models. One class of the models is usually developed in "academic papers" and typically serves to answer a few specific theoretical or practical questions mainly based on single-country models. The second class of the models is "practically oriented"[3]. These models are usually developed and maintained by multi-disciplinary teams of researchers and frequently assist policymakers in a broad range of possible questions and policy decisions.

The modeling approach of the first class of models is usually based on relatively small partial and general equilibrium models. More precisely, until 1990's environmental policies were mainly evaluated within partial equilibrium models. Within such setting, taxes/subsidies on environmentally harmful/beneficial goods were proved to be efficient and welfare-increasing. However, in early 1990's alternative agri-environmental policies were mainly evaluated within general equilibrium models in a second-best setting. At the time, there has been great interest in the possibility of substituting environmentally motivated or "green" taxes for ordinary income taxes. Some researchers have suggested that such revenue-neutral reforms might offer a "double dividend", i.e. not only to improve the environment but also to reduce certain costs of the tax system (Goulder, 1994). Even if the double-dividend proposition seemed obvious, the academic debate has focused on the general validity of such a ypothesis (FULLERTON and METCALF, 1997). It became clear that the validity of the double dividend hypothesis depends on the severity of a tax interaction effect, Pigouvian and revenue-recycling effect, price support effect, income replacement effect and trade effect which were found in literature (e.g. BOVENBERG and DE MOOIJ (1994), BOVENBERG and GOULDER (1995, 1996), PARRY (1999), PETERSON et al. (2002), TAHERIPOUR et al. (2008)). Analysis of nitrogen reduction policies in agricultural sector followed these general developments in agri-environmental policy evaluation. LANKOSKI and OLLIKAINEN (1999, 2003) used partial equilibrium approach in their analysis of optimal nitrogen reduction policies. In the analysis of policy for optimal provision of agri-environmental externalities authors used numerical parametric model for Finland, assuming heterogeneous land in multifunctional agriculture. Authors concluded that socially optimal policy implies differentiated fertilizer taxes and buffer strip subsidies. TAHERIPOUR et al. (2008) used large open economy general equilibrium approach in the presence of agricultural amenities. Authors concluded that evaluated market-based measures may generate a double dividend, while land retirement (regulatory measure) implies welfare losses.

To summarize, most of the mentioned academic papers analyzed market based agri-environmental measures and concluded that optimal policy scheme implies set of input taxes and subsidies that must be chosen jointly. Therefore, it seems that academics tend to favor market-based measures. On the other hand, policy makers usually base agri-environmental policies on regulatory measures. Although during the 1980's, and especially after 1990's, policymakers interest in the available market based measures grew significantly (EKINS, 1999), nitrogen reduction policies are still mostly based on regulatory measures. For example, agri-environmental policy in the EU is mostly based on directives and regulations. Directives are based on regulatory instruments while regulations consist of both, economic and regulatory instruments (OENEMA et al., 2011). Nitrates Directive (adopted in 1991), which is the most important policy aimed at nitrogen pollution reduction within the EU, is mostly based on regulatory measures. The US Environmental Protection Agency bases its agricultural nitrogen losses and emissions reduction policies on voluntary schemes and incentives (GRINSVEN et al., 2015), usually (non-tradeable) permits and regulations.

The second class of models uses complex large-scale dynamic CGE models which are designed to capture many imperfections (e.g. differences in substitutability of land and nitrogen, differences in small

[3] See footnote 1 for explanation. Therefore, "practically oriented" models are also published in academic journals and are used to investigate particular research questions. Also, "academic papers", although less sophisticated and simple, are useful from policy perspective point of view as their implications or modeling assumptions serve as inputs in relevant parts of large-scale models.

and large open economies, differences in substitutability of land between sectors, imperfect mobility of labor between agricultural and non-agricultural sectors[4] etc.). Most of the large-scale agri-environmental policy assessment models are based on Global Trade Analysis Project (GTAP)[5] model. GTAP itself has been extended in recent years to address environmental, climate, welfare, land, agriculture, and food security issues and their interactions with land resources. The augmented versions of this model have been frequently used to address the land-use, bio-fuel, greenhouse gases (GHG) and water related topics (TAHERIPOUR et al., 2013). MAGNET (Modular Applied GeNeral Equilibrium Tool) is a model which uses GTAP core to evaluate economic and environmental impacts of agricultural policies (including agri-environmental policies) related to the issues of bio-energy, sustainability and climate change (WOLTJER and KUIPER, 2014). MIRAGE-BioF is another GTAP based model designed for the analysis of biofuel policies and land use related policies. Besides its role in the analysis of the effects of biofuel policies, MIRAGE-BioF is also used to assess trade policy impacts and impacts of agricultural policies on income and poverty in developing countries (VALIN et al., 2013).

Therefore, CGE models are used as a standard tool for the quantitative analysis of policy interventions in many domains, including environmental policy. However, these types of models are often perceived as a black box (BÖHRINGER et al., 2003). This impression is partially the result of their complex structure, whereas BÖHRINGER et al. (2003) notice that scientific publications usually do not include a complete listing of the algebraic model underlying the numerical simulation nor the data used to calibrate model parameters. Most of the academic papers which use CGE approach to address agricultural nitrogen reduction policy issues apply it in the context of large open economies, which operate under the perfect competition and well-functioning labor markets. Additionally, alternative production technologies (whether nitrogen inputs are assumed to be substitutable in the agricultural production process or not) have not been considered as an important determinant of efficiency and welfare effects of nitrogen reduction policies. Furthermore, as PARRA-LÓPEZ et al. (2008) notice, although theoretical discussions can be found in the literature, only few reports integrate multifunctional agriculture[6] in the analysis of the sustainability and the global welfare of society.

On the other hand, very well documented CGE models used for agri-environmental policy impact assessment have a very complex structure. Due to their complexity it is usually hard to track which features of the model generate certain results. Additionally, except for the experimental GTAP model for the US (see LIU et al., 2018), these models have not been used for the analysis of nitrogen reduction policies. Moreover, multifunctionality of agriculture is still not included as an additional source of market failure in agri-environmental policy assessment models.

While acknowledging multifunctionality of agriculture, this paper seeks to analyze the implications of labor market disequilibrium and the degree of substitutability of nitrogen in agricultural production for agricultural nitrogen reduction policy prescriptions in a small open economy. Policy prescriptions are derived from the estimated welfare and general equilibrium effects of different policy options.

3 Model Assumptions

3.1 An Overview

This sub-section introduces initial assumptions and the structure of the Croatian data based models which consists of seven aggregated sectors (see Table 1A in Appendix).

Before going into details regarding the assumptions and the structure of the model, some limitations and justifications should be pointed out. First, unlike industrial carbon pollution, agriculture is a non-point source polluter and the nitrogen use in agriculture is mainly characterized by heterogeneity and uncertainty. This means that the amount of nitrogen emissions

[4] The results of the models in which agricultural labor is assumed to be immobile between sectors (modelled as in GILBERT and TOWER, 2013) are not presented due to their insignificance for the overall conclusions.

[5] GTAP is a global CGE model which traces production, consumption, and trade of a wide range of goods and service across the world while taking into account market clearing conditions and resource constraints.

[6] Multifunctionality refers to the fact that an economic activity may have multiple outputs and, by virtue of this, may contribute to several societal objectives at once. Multifunctionality is thus an activity oriented concept that refers to specific properties of the production process and its multiple outputs (OECD, 2001, 2008).

largely varies from one farm to another because many factors (soil quality, crop produced, fertilization and irrigation techniques used, etc.) which lead to a heterogeneous contribution to nitrogen diffuse pollution. At disaggregated (micro) level these characteristics play a crucial role and any research aiming to analyze nitrogen pollution reduction policies more realistically at disaggregated level should decompose the whole agricultural sector into different subsectors with similar nitrogen cycle. To be able to use CGE modeling techniques at more disaggregated level, data and modeling requirements are large. The data requirements include regional input-output tables which decompose the agricultural sector into similar nitrogen cycle subsectors and detailed data regarding various nitrogen inputs and outputs and nitrogen balances for agricultural sub-sectors. This in turn requires detailed estimates of nitrogen leaching functions and marginal damage costs. Since those data are not available at this point (OECD, 2012) this paper explores average macroeconomic effects of nitrogen pollution reduction policies within the agricultural sector. The obtained results will lead to some general conclusions regarding the (average) effects of selected nitrogen reduction policies at macro-level but will not generate any conclusions regarding the potential effects at farm and agricultural product level. The micro-level results can differ significantly from those calculated at macro level. However, the conclusions regarding the importance and impact of different assumptions, i.e. level of substitutability of nitrogen in agricultural production and market imperfections, would be of the same direction at both the micro and macro level. The magnitude would be different, depending on the marginal damage of specific subsector or product, farm and other relevant factors. However, at high level of aggregation and in accordance with the (macro-level) objectives of this study the non-point source nature of nitrogen pollution in agriculture should not reverse the findings.

Social accounting matrix (SAM) and assumed parameters are given in Tables 2A, 3A and 4A in the Appendix. Except for the assumptions presented in this section, model follows assumptions and structure of a standard small open economy CGE model with unemployed labor force in equilibrium[7]. Unemployment is generated by the following Phillips type relation

$$[(P_L{}^1/CPI^1)/(P_L{}^0/CPI^0)-1] = \text{Phillips}[(U_N{}^1/L_s{}^1)/(U_N{}^0/L_s{}^0)-1] \tag{1}$$

In Equation (1) Phillips represents negative parameter which reflects the adverse impact of unemployment rate (U_N/L_s) on consumer price index (CPI).

3.2 Environmental Impacts of Agriculture and Social Welfare

Environmental impacts of agriculture enter social welfare function as in TAHERIPOUR et al., (2008). It is assumed that utility is separable and linear in two environmental outputs: nitrogen pollution (E_N) and environmental benefits (E_B). Nitrogen pollution is assumingly positive and linear function of nitrogen fertilizers applied in agricultural sector ($XD_{I,A}$, $XD_{BC,A}$). The utility function is given by the following linear expenditures system (LES) function:

$$\max U = \beta\prod_{i=1}^{7}(C_i-\mu_i)^{\alpha_i} - \varphi E_N + \theta E_B \tag{2}$$

where

$$E_N = f(XD_{BC,A}) \tag{3}$$
$$E_B = Z_A$$

$$\varphi = MSC(XD_{BC,A}) > 0 \tag{4}$$
$$\theta = MSB(Z_A) > 0$$

In Equation (2) C_i is consumer demand for products of i-th sector, E_N is monetary value of nitrogen fertilizers used in agricultural production, E_B is agricultural land. $\alpha_i's$ are powers of LES utility functions for i-th good, μ_i stands for subsistence level of consumption of i-th good. φ and θ are assumed marginal cost of nitrogen pollution and marginal benefit of agricultural land.

The linearity assumption may seem too simplistic. However, the construction of agricultural nitrogen pollution conversion factor considers the characteristics that affect the excess nitrogen generation (i.e. soil quality, crop produced, fertilization techniques used). More precisely, conversion factor is calculated as gross nitrogen balance (GNB) per monetary unit of nitrogen fertilizers applied in agricultural sector, whereas the methodology of GNB calculation considers different dimensions of nitrogen inputs and outputs (EUROSTAT, 2016).

[7] The core structure of the model is based on ECOMOD (2015).

There is a large degree of uncertainty regarding the assumed social costs and benefits of environmental outputs of agriculture. According to BRINK et al. (2011) total reactive nitrogen pollution damage cost amounts to 1-4% of average European income, which on average gives a social cost of 2.5% of European income. On the other hand, the average total agricultural landscape benefits estimate, measured by willingness to pay (WTP) in 2009, varies between 0.13%-0.25% of European income (CIAIAN and PALOMA, 2011). Due to relatively low estimates of agricultural landscape benefits, the net social cost of agriculture is set at 2.5% of total expenditures on consumers goods[8]. MSC (φ) of agricultural nitrogen pollution is set at 10 EUR per kg of pollutant, which is the lower bound estimate in BRINK et al. (2011). Nitrogen pollution is approximated by gross nutrient balance in agriculture (GNB_A). According to Eurostat's (2016) GNB_A estimates, Croatia has a relatively high potential surplus of nitrogen on agricultural land. GNB_A is defined as:

$$GNB_A = NOxFACTOR_A * NOxSHARE_A * \left(XD_{BC,A}\right), \quad (5)$$

where $NOxFACTOR_A$ equals to:

$$NOxFACTOR_A = \frac{GNB_A^0}{XD_{BC,A}^0}. \quad (6)$$

$NOxFACTOR_A$ is the conversion factor calculated as GNB per monetary unit of nitrogen fertilizers applied in agricultural sector which is observable in initial equilibrium (GNB_A^0 and $XD_{BC,A}^0$). $NOxSHARE_A$ is the share of chemical industry in agricultural intermediate demand for goods within the relevant industry (BC). MSB (θ) of additional unit of utilized agricultural area is set at 142 EUR per ha, which is an average estimate in CIAIAN and PALOMA (2011).

[8] By assuming these values, it is presumed that the social cost of nitrogen pollution in Croatia corresponds to the average calculated for the EU in 2011. Since Croatia is one of the poorest EU countries, it is reasonable to assume that society values the environment less then richer societies. From the perspective of the level of development in Croatia and how the level of development connects to the society's valuation of environment, other reasonable values for these parameters would probably be lower than the ones assumed in this paper, and therefore, would not reverse theoretically inconsistent findings presented in subsection 4.1.1.

3.3 Alternative Production Technologies

To assess implications of alternative production technologies on welfare and environmental effects of alternative agricultural nitrogen reduction two different modeling assumptions are employed. At the one end nitrogen fertilizers are assumed to be substitutable (not perfectly) in agricultural production process. At another end Leontief type technology is assumed for all intermediates, including nitrogen fertilizers.

The latter assumption is usually employed in a standard CGE modelling framework. By changing the substitutability options, it is possible to determine the role of physical conditions (e.g. quality of land and natural soil nitrogen supply) in the determination of efficiency and welfare effects of alternative agricultural nitrogen reduction policies. Alternative production technologies are presented in Table 3A.a (substitution allowed) and Figure 1A (substitution not allowed) in Appendix.

In the first setting, in which nitrogen fertilizers are assumed to be substitutable in production process, producers face 3-level nested production function. At the first level, capital-labor-land-BC good (agricultural intermediates which contain chemical industry products) input bundle ($KLZB_i$) and intermediates without BC sector goods ($IO_{i,ni}$) are combined using Leontief technology. At the second level, capital and labor bundle (KL_i) and land and BC good bundle (ZB_i) are combined using Cobb-Douglas production technology. At the third level producers choose the combination of capital and labor (KL_i) given the constant elasticity of substitution (CES) production function. At this level producers also choose the combination of land and BC sector good given the Cobb-Douglas production technology.

In the alternative model setting, in which nitrogen fertilizers are assumed to be complements in production process, producers also face 3-level nested production function. At the first level producers maximize profits facing Leontief technology with capital-labor-land input bundle (KLZ_i) and intermediates ($IO_{i,h}$) as factors of production. At the second level producers choose the combination of capital and labor (KL_i) and land (Z_i) given the Cobb-Douglas production technology. At the third level capital and labor (KL_i) are combined using CES production function (see Figure 1A in Appendix).

The following section analyzes efficiency and welfare effects of the nitrogen pollution reduction measures in Croatian data-based CGE model within alternative model settings.

4 Efficiency, Welfare and General Equilibrium Effects of Selected Nitrogen Pollution Reduction Policies: Theory vs ex-ante Quasi-Empirical Evidence from Croatia

4.1 Efficiency and Welfare Effects of Selected Nitrogen Pollution Reduction Policies: Implications of Technology of Production

This section evaluates efficiency and welfare effects of nitrogen pollution reduction policies depending on the underlying technology of production. Evaluated nitrogen reduction policies in alternative model settings include the following market-based measures: agricultural good tax, nitrogen tax in agriculture, state budget revenues neutral agricultural good tax (labor/income taxes), state budget revenues neutral nitrogen tax (labor/income taxes), nitrogen tax in agriculture and agri-land subsidy as well as state budget neutral agri-land subsidy (commodity taxes). The analysis also includes two command-and-control measures, i.e. max nitrogen allowed in agriculture and min agri-land required.

The main goal of this part of the paper is to analyze if the efficiency and welfare effects of nitrogen pollution reduction policies depend on the assumed technology of production. The term efficiency is used to describe the potential of a particular policy to reduce the nitrogen usage by targeted amount (1%, 5%, 10% and 20%). In the case of efficient policies, simulation results are presented for 1%, 5%, 10% and 20% nitrogen reduction targets.[9] In the case of inefficient policies, i.e. policies which fail to reach nitrogen reduction target, simulation results are presented for 1%, 5%, 10% and 20% land extension targets.[10]

Welfare change is measured by equivalent variation (EV):

$$EV = E(p_i^0, U^1) - E(p_i^0, U^0) \qquad (7)$$

In Equation (7) p_i^0 are prices of goods in initial equilibrium, U^0 is utility level in initial equilibrium and U^1 is utility level in post-policy implementation equilibrium. Utility levels in initial and post-policy implementation equilibrium are calculated using Equation (2).

3.1.1 Market-Based Measures

Introduction of agricultural good tax is simulated as an increase of consumption tax rate in agricultural sector until the nitrogen reduction target is reached.[11] The first-round effects of increased consumption tax rate in agricultural sector reduce the household consumption (see Equation (1) in Table 3A.a. in Appendix) and increase government revenues (see Equation (17) in Table 3A.a. in Appendix), consumer prices (see Equation (32) in Table 3A.a. in Appendix) and unemployment rate (see Equation (38) in Table 3A.a. in Appendix).

Introduction of nitrogen tax is simulated as an increase of tax rate on agricultural intermediates which contain chemical industry products (BC sector) until the nitrogen reduction target is reached. Increased nitrogen tax in agriculture changes the general equilibrium by reducing the agricultural sector intermediates and land demand (see Equation (4), (8) and (9) in Table 3A.a. in Appendix) and by increasing government revenues see Equation (17) in Table 3A.a. in Appendix).

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[9] Approximated using agricultural intermediate demand for chemical industry products within BC sector.

[10] Note that it is assumed that the supply of land is fixed and is equal to the sum of all sectors' land demand. It is assumed that sectors other than agriculture own land that can be utilized (and demanded by) in agricultural sector. The use of this modelling approach allows agricultural sector to increase utilized land. Obviously, this approach might be problematic for several reasons. However, this modelling decision is based on the following reasoning 1) plenty of underutilized agricultural land in Croatia suggests that the use of more land in agriculture should be allowed (according to the Environmental Protection Agency (EPA) the total agricultural area in Croatia amounted to 2,767,000 ha in 2011, of which 1,548,000 ha refers to land under crops (perennial and annual crops), and the remaining 1,219,000 ha represent underutilized agricultural land under threat of succession and thus at risk of permanent loss of biodiversity and landscape diversity), and 2) land is a minor factor of production in most economic activities (please see note under the Table 2A in Appendix), and therefore, land mobility should not affect other sectors in such a way that it would reverse the findings for Croatia.

[11] The analysis consists of two steps: 1) finding the solutions for different tax/subsidy rates (in some reasonable range), and 2) calculating implied nitrogen reduction. When model gives 1%, 5%, 10% and 20% nitrogen reduction as the solution of imposing particular tax/subsidy rate, the macroeconomic and welfare effects are analyzed in that solution.

Introduction of nitrogen tax and agri-land subsidy is simulated as a simultaneous increase of tax rate on agricultural intermediates which contain chemical industry products (BC sector) and agri-land subsidies until the nitrogen reduction target is reached. Increased nitrogen tax in agriculture changes the general equilibrium as described before, while land subsidies increase agricultural sector demand for land (see Equation (4), (8) and (9) in Table 3A.a. in Appendix) and decrease government revenues (see Equation (17) in Table 3A.a. in Appendix). The net effect on government revenues is ambiguous due to reverse effects of taxes and subsidies.

Introduction of a commodity-taxes and agri-land subsidy is simulated as a simultaneous change in commodity taxes and introduction of agri-land subsidies. The policy assumes that government revenues remain the same in the post and pre-policy equilibrium. The transmitting mechanisms of this policy work through change in agricultural land demand (see Equation (4), (8) and (9) in Table 3A.a. in Appendix), household consumption (see Equation (1) in Table 3A.a. in Appendix), consumer prices (see Equation (32) in Table 3A.a. in Appendix) and unemployment (see Equation (38) in Table 3A.a. in Appendix). Additionally, we assess if the substitution of existing distorting taxes by environmentally motivated taxes has the potential to mitigate adverse general equilibrium effects of taxes-based nitrogen reduction measures in Croatia. This type of analysis implies simultaneous change of environmental and labor or income taxes that leave state budget revenues unchanged. Therefore, in the case of state revenue neutral environmental taxes, increased agricultural goods and nitrogen input taxes are accompanied by lower labor taxes (implemented as change of t_l in Equations (11)-(13) and (17) in Table 3A.a. in Appendix) or income taxes (implemented as change of t_Y in Equations (1), (2) and (17) in Table 3A.a. in Appendix). Figures 1.a) and 1.b) show the welfare change after the new (post-policy) equilibrium is reached upon the introduction of all market-based measures. Welfare effects are measured as percentage share of the equivalent variation in consumption expenditures (EV (%C)). Parts a) and b) of Figure 1 show the simulation results depending on the level of substitutability of nitrogen fertilizers in agricultural production process.

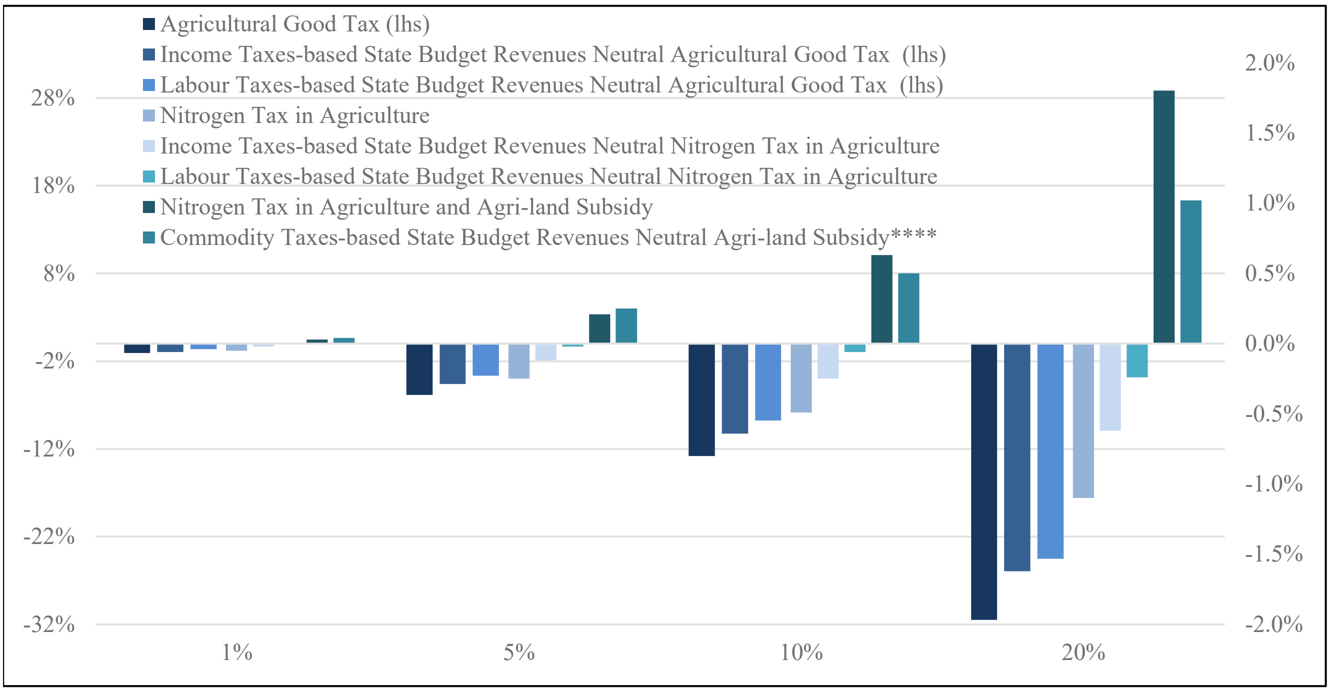
Simulation results suggest that the technology of production determines the welfare effects of market-based nitrogen reduction measures. The comparison of the welfare effects in a) and b) parts of Figure 1 unambiguously shows that the social welfare costs/gains are much higher/lower when substitution of nitrogen fertilizers is not allowed. Specifically, much higher taxes are needed to achieve the same nitrogen reduction target under the complementarity versus substitutability assumption. Hence, higher implied taxes increase makes most of the market-based policies (socially) costlier under the complementarity assumption. This might be especially important in countries (and for crops) with low biological nitrogen fixation or with limited possibilities for agricultural land extension.

Figure 1 shows that regardless of the underlying technology of production, both purely taxes-based measures (agricultural good tax and nitrogen tax in agriculture) are efficient, i.e. successful in reaching the nitrogen pollution reduction targets regardless of the underlying technology. However, both taxes-based measures always reduce welfare in Croatia. Similarly, regardless of the technology of production, nitrogen tax in agriculture is superior to agricultural good tax due to lower social costs of nitrogen reduction. Social costs of both measures can be mitigated by state budget neutral compensation of newly introduced agri-environmental taxes (i.e. by lowering labor and income taxes upon introduction of taxes-based measures). Although neutralization reduces social costs of these measures it is unable to fully offset their adverse welfare effects.

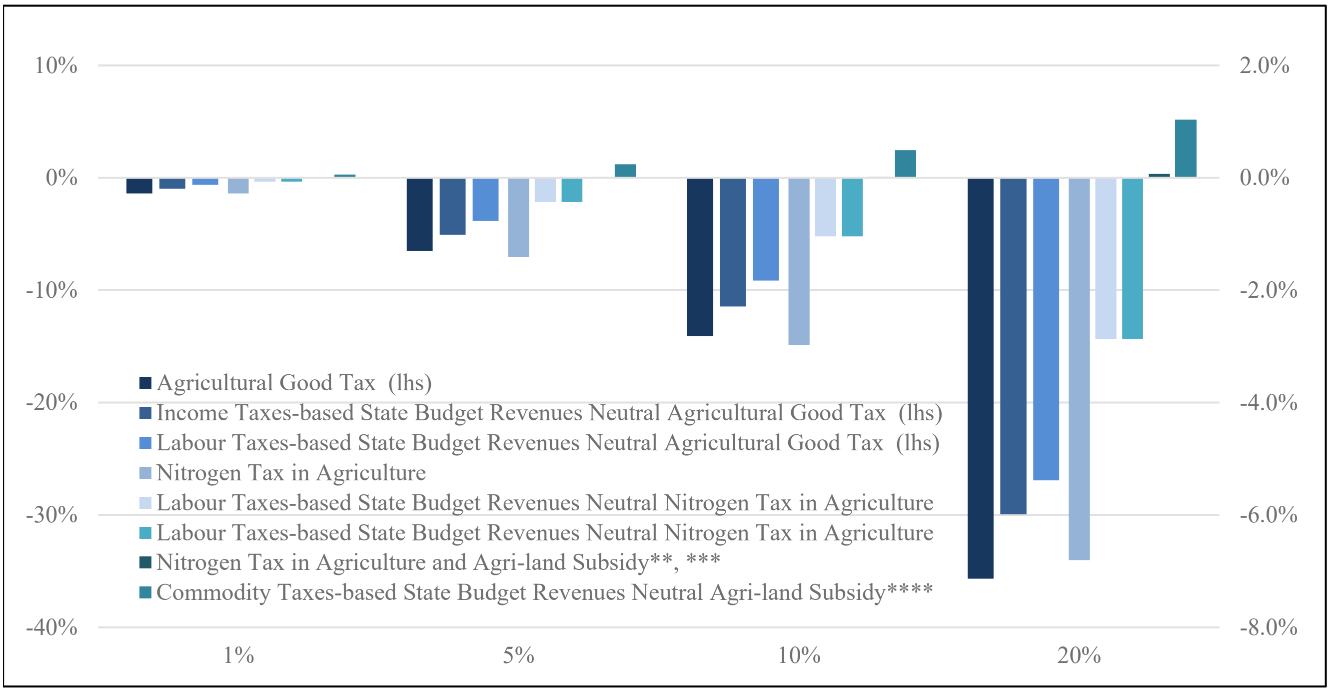
Figure 1.a also shows that nitrogen tax in agriculture and agri-land subsidy generates welfare gains in all models at all nitrogen reduction targets. This is the only efficient nitrogen reduction policy (up to 17%) in Croatia which has the potential to increase welfare (but only under the substitutability assumption). Note that in the Figure 1.b results for Croatia show welfare gains for alternative environmental goal (i.e. agri-land extension targets). Namely, nitrogen tax in agriculture and agri-land subsidy becomes inefficient in reaching the nitrogen reduction targets under the complementarity assumption. Additionally, Figure 1 shows that state budget neutral agri-land subsidy (neutralization based on commodity taxes) generates the largest welfare gains. However, note that the results in both parts of Figure 1 are presented for 1%, 5%, 10% and 20% agri-land extension targets, meaning that this policy fails to reduce nitrogen use in agriculture, i.e. it is inefficient and can't be used as a policy directed towards agricultural nitrogen pollution reduction regardless of the underlying technology.

Figure 1. Welfare effects* of market-based measures

a) Substitution allowed



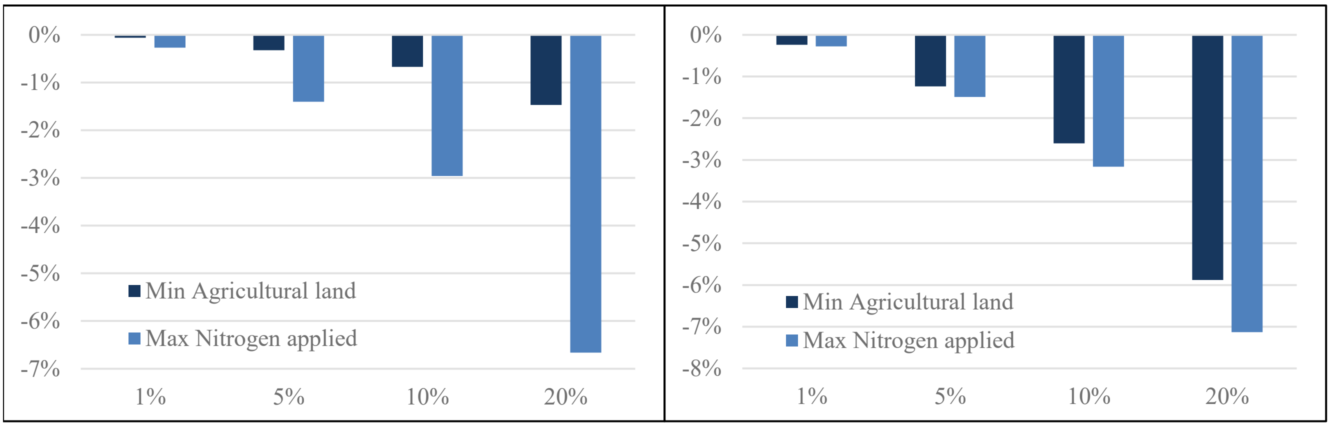
b) Substitution not allowed



Notes: *Nitrogen reduction target (or agricultural land extension target) is shown on horizontal axis. Welfare effects are shown on vertical axis and are calculated as the percentage share of the equivalent variation (welfare change) in household's consumption expenditures (EV (%C)).
**This policy is efficient up to 17% nitrogen reduction target. Therefore, the last bar shows the welfare change for 17% nitrogen reduction target.
***Under the complementarity assumption (b) Substitution not allowed this policy fails to reduce nitrogen usage in agriculture in Croatia. Simulation results under the complementarity assumption are presented for 1%, 5%, 10% and 20% land extension targets.
****Under the both assumptions (substitution allowed and not allowed) this policy fails to reduce nitrogen usage in agriculture. Simulation results under the substitutability and complementarity assumption for all types of models are presented for 1%, 5%, 10% and 20% land extension targets.
Source: author

Figure 2. Welfare effects of command-and-control based measures

a) Substitution allowed b) Substitution not allowed



Note: nitrogen reduction target is shown on horizontal axis. Welfare effects are shown on vertical axis and are calculated as the percentage share of the equivalent variation (welfare change) in household's consumption expenditures (EV (%C)).
Source: author

Therefore, the results indicate that combined (subsidies and taxes based - nitrogen tax in agriculture and agri-land subsidy as well as state budget neutral agri-land subsidy) nitrogen reduction measures generate welfare gains. However, the efficiency in reaching the nitrogen pollution reduction targets of nitrogen tax in agriculture and agri-land subsidy largely depends upon assumed technology of production. On the other hand, state budget neutral agri-land subsidy fails to reduce agricultural nitrogen pollution regardless of the assumed technology of production.

To summarize, when nitrogen is substitutable in production process, most of the evaluated market-based measures are efficient in reaching the nitrogen pollution reduction targets in Croatia. However, their introduction implies welfare costs in most cases. Agricultural good tax reduces the welfare the most, even when neutralized by income and labor taxes. Social costs of nitrogen taxes can be substantially reduced by simultaneous decrease of labor taxes subject to unchanged state budget revenues. Nitrogen tax and agri-land subsidy is the only welfare improving measure that has the potential to decrease agricultural nitrogen pollution (up to 17%), while state budget neutral agri-land subsidy (although welfare increasing) is not efficient. Under the complementarity assumption, ranking of policies (based on the lowest social costs criteria) resembles the ranking under the substitutability assumption. However, social costs of most measures become higher and, more important, the only efficient welfare increasing measure, i.e. nitrogen tax and agri-land subsidy, becomes inefficient and can't be used to reduce agricultural nitrogen pollution.

3.1.2 Command-and-Control Based Measures

Maximum nitrogen consumption allowed in agriculture is simulated by exogenously setting the level of intermediates which contain chemical industry products on the level defined by nitrogen reduction target (see Equation (8) in Table 3A.a. in Appendix). Similarly, minimum agri-land required[12] is simulated by exogenously setting the level of agricultural land on the level defined by nitrogen reduction target (see Equation (9) in Table 3A.a. in Appendix). Both quantitative requests are transmitted through changes in agricultural producers' intermediate goods and factor demands.

Figure 2 shows the welfare change after the new (post-policy) equilibrium is reached upon the implementation of command-and-control based measures. As before, welfare effects are measured as percentage share of the equivalent variation in consumption expenditures (EV (%C)). Parts a) and b) of Figure 2 show the simulation results depending on the level of substitutability of nitrogen fertilizers in agricultural production process.

[12] Depending on the assumed substitutability of land and nitrogen in agricultural production, this policy can vary as far as nitrogen reduction is concerned. Namely, under the reasonable assumptions regarding the substitutability of land and nitrogen, nitrogen pollution reduction can be achieved, although it would be modest. However, under the complementarity assumption this measure is not able to reduce the agricultural nitrogen pollution and should be viewed as a measure to increase agricultural amenities, which might be interesting from multifunctional agriculture point of view.

Simulation results suggest that the technology of production determines social costs of command-and-control-based nitrogen reduction measures. As expected, the comparison of the welfare effects in parts a) and b) of Figure 2 shows that the social welfare costs are somewhat higher when substitution of the nitrogen fertilizers in agriculture is not allowed. However, increase of social welfare costs is lower than in the case of welfare reducing market-based measures (agricultural good and nitrogen taxes). Minimum agri-land requirements are superior to maximum nitrogen input allowances due to the lower implied social costs.

By comparing the welfare costs of agricultural goods taxes and command-and-control measures in Croatia (Figures 1 and 2) it is evident that command-and-control policies imply lower social costs than evaluated agri-environmental taxes (uncompensated taxes-based measures). Additionally, from a social welfare point of view, command-and-control measures are superior to agricultural good tax even when it is compensated by lower income and labor taxes.

The results also suggest that the technology of production is not an important determinant of the efficiency of command-and-control nitrogen reduction measures. Both measures are efficient in reaching the targeted nitrogen pollution reduction regardless of the level of substitutability of nitrogen fertilizers in agricultural production.

4.2 General Equilibrium and Environmental Effects of Nitrogen Pollution Reduction Policies: Implications of Labor Market Imperfections and Multifunctionality

The analysis of efficiency and welfare effects of evaluated nitrogen reduction policies in the previous section lead to several conclusions:

a) Available technology of production is an important determinant of welfare effects of agri-environmental nitrogen reduction policies. Although most of the efficient policies remain efficient regardless of the assumed technology of production, environmental targets are achieved at higher social costs.

b) Implementation of agricultural nitrogen reduction measures based on taxes always reduces welfare in Croatia. This finding contradicts usual theoretical environmental taxation conclusions (see any environmental economics textbook) as well as some previous research findings. For example, PARRY (1997) concludes that revenue-raising can be a necessary condition for environmental policies to increase welfare which essentially implies some form of environmental taxation while TAHERIPOUR et al. (2008) conclude that all alternative market-based policies which they consider, except land retirement which is regulatory measure, may generate welfare gains in USA.

c) Combined (taxes and subsidies-based) agricultural nitrogen reduction policies are welfare enhancing in Croatia. Although welfare enhancing, these policies are not always successful in reaching nitrogen reduction targets in Croatia, i.e. are not efficient. Namely, the only efficient policy which has the potential to increase welfare in Croatia is the one that combines nitrogen tax and agri-land subsidy. This finding is in line with previous optimal agri-environmental policy research conclusions. For example, LANKOSKI and OLLIKAINEN (1999, 2003) conclude that in Finland the socially optimal policy implies differentiated fertilizer taxes and buffer strip subsidies and that at 30% nitrogen run-off abatement goal, optimal policy mix implies higher fertilizer tax compensated by higher acreage subsidy while PETERSON et al. (2002) find that optimal policy scheme implies a complex set of input taxes, subsidies or regulations that must be chosen jointly. However, this policy becomes inefficient under the complementarity assumption, at least in Croatia. Although this conclusion might not be relevant from macro perspective, as nitrogen fertilizers can be considered substitutable in production process (on average), it might be relevant from the perspective of policy choices for crops with different degree of nitrogen fertilizers substitutability.

d) In line with theoretical conclusions (see any environmental economics textbook) as well as some previous research findings (e.g. PARRY (1997) and TAHERIPOUR et al. (2008)), implementation of command-and-control based nitrogen pollution reduction measures decreases social welfare. However, welfare losses of command-and-control measures in Croatia are lower than those of taxes-based measures (especially when compared to agricultural good tax, even when it is compensated by labor and income tax reductions). In line with b), this finding contradicts theoretical and some previous applied research findings.

The main goal of this part of the paper is to explain differences and similarities between Croatian data-based findings and theoretical as well as previous research conclusions. With the aim of doing so, we analyze macroeconomic effects of evaluated nitrogen reduction policy measures. It turns out that welfare effects crucially depend on labor market response to evaluated measures. We also analyze the role of multifunctional agriculture in the determination of welfare effects of evaluated measures. It seems that most of the evaluated (efficient) policies decrease agricultural land (exceptions include the combination of nitrogen tax in agriculture and agri-land subsidy as well as min agri-land requirements) and therefore reduce possible environmental welfare gains. The focus of this section is on model setting which allows nitrogen substitution in agriculture.

4.2.1 Market-Based Measures

To put the results for Croatia into the perspective of previous research findings and environmental taxation theory, and to reveal transmission mechanisms at work, this part of the paper evaluates GDP and unemployment changes after the taxes-based policies implementation. Note that in textbook models new taxation creates minimal distortions. Therefore, welfare gains of reduced nitrogen pollution can be high enough to more than offset welfare losses due to production decrease induced by environmentally motivated taxation.

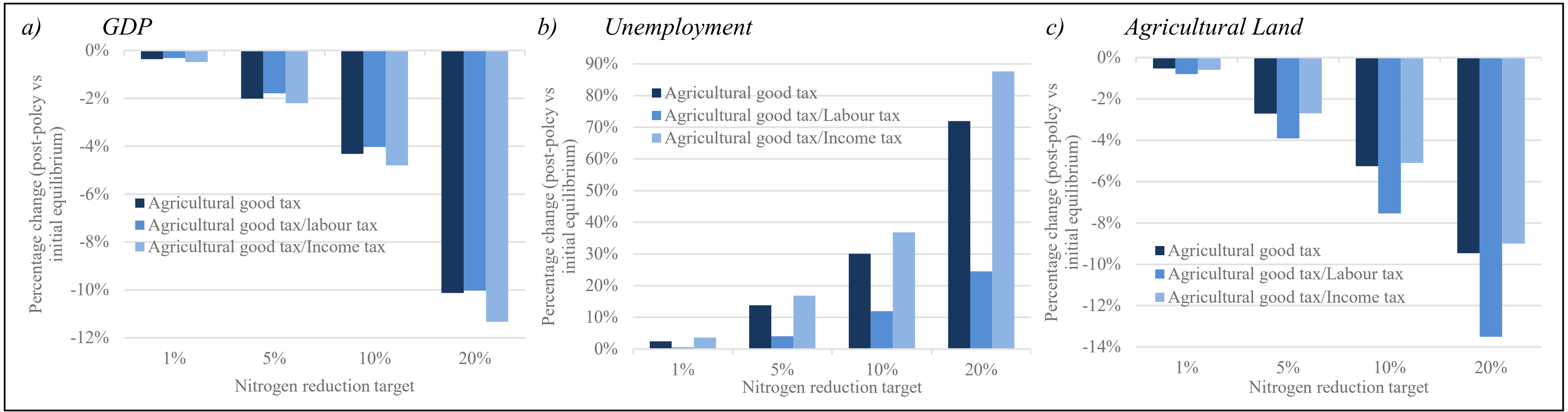
On the other hand, introduction of taxes-based nitrogen reduction measures builds upon several market distortions in Croatia. Most notable differences in initial settings of textbook and most of the applied "academic" papers and Croatian data-based model are high unemployment rate (i.e. labor market disequilibrium) and high tax burden in Croatia. Therefore, nitrogen reduction requires relatively large increases of already high taxes, especially in the case of agricultural good tax[13]. Simulated responses of GDP and unemployment rate change after the implementation of taxes-based nitrogen reduction policies in Croatia are presented in Figures 3 and 4. It is evident that labor market disequilibrium governs these differences, since introduction of new taxes increases the unemployment rate (see Figure 3.b and 4.b) that was already high in initial equilibrium when it reached 11.7%. Adverse effects of higher unemployment rate on GDP are amplified by the effects of new taxes in the presence of initially high tax burden (see Figure 3.a and 4.a) in Croatia. Both changes (higher unemployment and tax burden) induce welfare losses which can't be offset by nitrogen pollution reduction welfare gain. Additionally, environmental welfare gains due to the nitrogen pollution reduction are partially reversed due to the effects of taxes-based policies on agricultural land. As figures 3.c and 4.c show, both taxes reduce agricultural land from its 1.5 billion Croatian kuna value in initial equilibrium, and therefore, decrease environmental welfare gain.

As mentioned previously, to assess if the substitution of existing distorting taxes by environmentally motivated taxes has the potential to mitigate adverse general equilibrium effects of taxes-based measures in Croatia, we simulated the effects of simultaneous change of environmental and labor/income taxes which leave the state budget revenues unchanged. Simulation results presented in Figures 3 and 4 show that substitution of nitrogen taxes by labor taxes has the smallest adverse effects on unemployment and income. Since lower labor taxes increase real wage, adverse effects of nitrogen taxes on unemployment are mitigated. Still, it seems that in the presence of several market distortions in Croatia one should not expect double dividends from budget revenue neutral nitrogen reduction related taxes. On top of that, due to the fact that small open economies can't influence world prices (PETERSON et al. (2002)), Croatia is unable to transfer at least a part of its nitrogen reduction policies costs to world markets. Therefore, implied competitiveness loss hinders taxes-based nitrogen reduction policies potential to induce welfare gains in Croatia.

Regarding the combined (taxes and subsidies based) nitrogen reduction policies, results are in line with some previous research findings, especially in the case of nitrogen tax in agriculture and agri-land subsidy (e.g. LANKOSKI and OLLIKAINEN (1999, 2003) and PETERSON et al. (2002)). In the case of budget revenues neutral agri-land subsidy it is hard to find comparable experiment, but note that the introduction of subsidies within theoretical model has to be followed by an increase of existing (non-distortive) taxes or by introduction of new (distortive) taxes. Introduction of new taxes in these models would lower the welfare gains of combined policies in theoretical general equilibrium models. In Croatia this measure implies lower taxes due to favorable labor

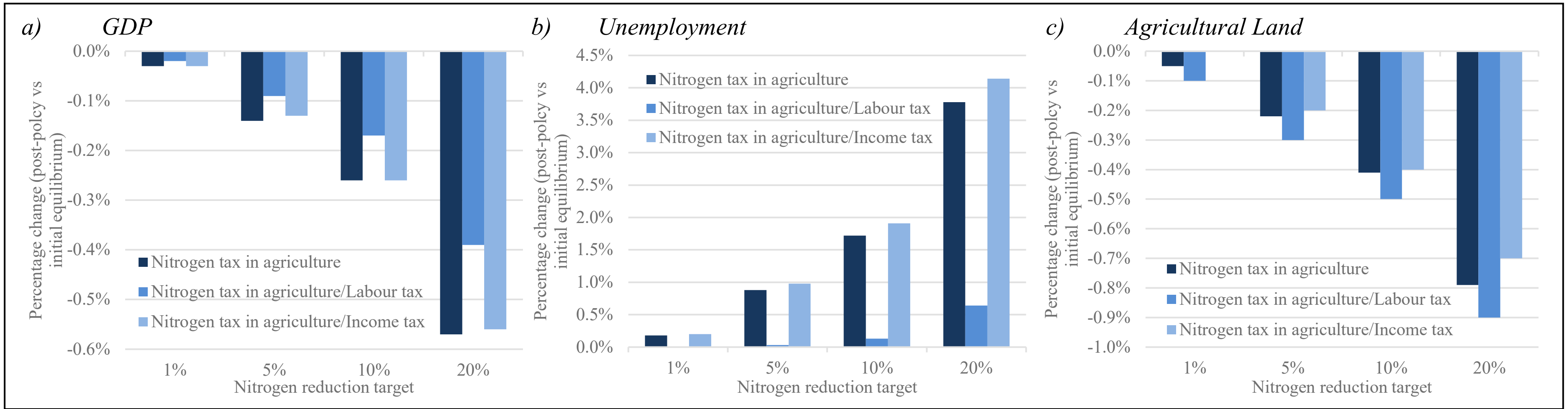
[13] Due to the space limitations implied tax changes upon implementation of evaluated agricultural nitrogen reduction policies are not showed. Implied tax changes are available upon request.

Figure 3. General equilibrium and environmental effects of agricultural good tax in Croatia (QEM, substitution allowed)



Note: nitrogen reduction target is shown on horizontal axis. General equilibrium effects are shown on vertical axis and are calculated as the percentage change of GDP, unemployment and agricultural land in new (post-policy implementation) equilibrium (in comparison to initial equilibrium).
Source: author

Figure 4. General equilibrium and environmental effects of nitrogen tax in agriculture in Croatia (QEM, substitution allowed)



Note: nitrogen reduction target is shown on horizontal axis. General equilibrium effects are shown on vertical axis and are calculated as the percentage change of GDP, unemployment and agricultural land in new (post-policy implementation) equilibrium (in comparison to initial equilibrium).
Source: author

market effects which are impossible in models in which labor market clears in equilibrium. The latter assumption is employed in both textbook and most of the comparable applied research. Generally, results for Croatia (presented in Figure 5) show that land subsidies could be necessary to generate nitrogen reduction related welfare gains. Thus, the only efficient and welfare increasing nitrogen reduction policy in Croatia implies simultaneous introduction of nitrogen tax in agriculture and agri-land subsidy. Although this policy increases unemployment, land subsidies offset its adverse effects on gross domestic product (GDP) and increase agricultural environmental benefits (see Figure 5.a). However, this conclusion is valid only under the nitrogen substitutability assumption as argued in Section 4.1.1. Namely, under the complementarity assumption this policy fails to reduce agricultural nitrogen pollution due to the effects of land subsidy on land and employment expansion which (due to assumed complementarity of nitrogen and land) increases the usage of nitrogen fertilizers.

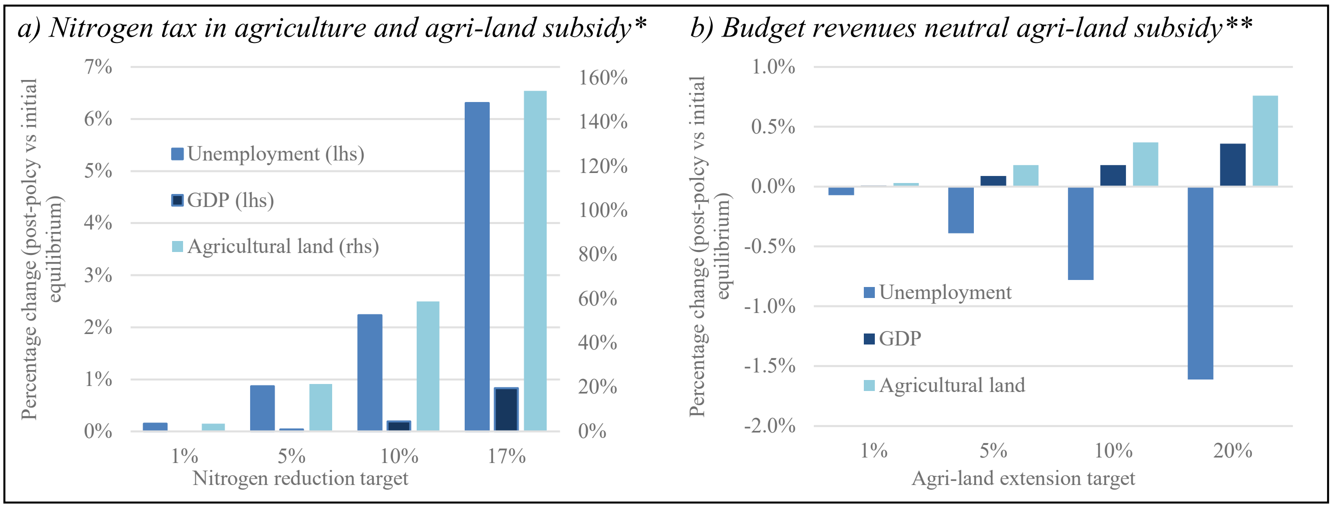
State budget neutral agri-land subsidy fails to reduce agricultural nitrogen pollution in Croatia due to its favorable effects on unemployment and consequent income growth (see Figure 5.b). Namely, as noted on multiple occasions, in Croatia state budget revenue neutralization implies lower commodity taxes upon introduction of land subsidies.

4.2.2 Command-and-Control Based Measures

In line with the theoretical and applied research conclusions, implementation of command-and-control based nitrogen pollution reduction measures decreases social welfare in Croatia. However, welfare losses are lower in the case of command-and-control measures than in the case of taxes-based measures which somewhat contradicts theoretical and previous research findings (see any environmental economics textbook as well as some previous research findings (e.g. PARRY (1997) and TAHERIPOUR et al. (2008)). Results show that both analyzed command-and-control policies increase unemployment and decrease income significantly less than agricultural good tax (see Figures 3 and 6).

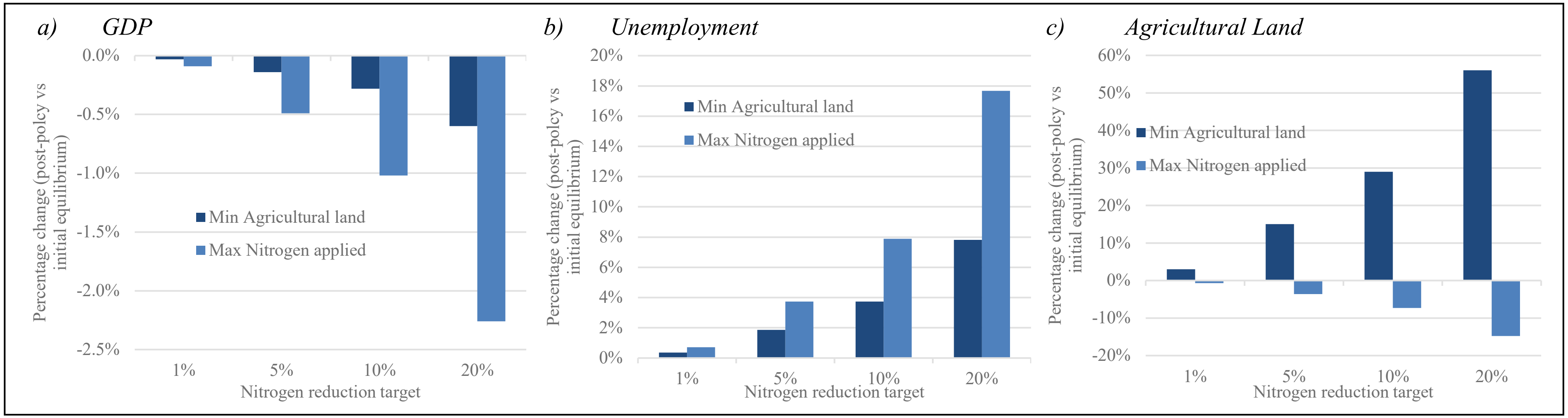
As argued in section 4.1.2., minimum agri-land requirements measure is superior to maximum nitrogen input allowances in agriculture due to lower implied social costs. Lower social costs of minimum agri-land requirements are mostly the result of less pronounced decline of GDP and unemployment growth (see Figure 6). However, it should be noted that assumed multifunctionality of agriculture also affects social costs of these policies. Namely, minimal agricultural land requirement increases agricultural land and reduces nitrogen fertilizer application simultaneously (see Figure 6). Both changes (agricultural land increase and nitrogen consumption reduction) increase social welfare by lowering environmental costs and increasing environmental benefits of agriculture.

Figure 5. General equilibrium and environmental effects of combined agricultural nitrogen reduction measures in Croatia (QEM, substitution allowed)



Note: *nitrogen reduction target is shown on horizontal axis. General equilibrium effects are shown on vertical axis and are calculated as the percentage change of GDP, unemployment and agricultural land in new (post-policy implementation) equilibrium (in comparison to initial equilibrium).
**State budget neutral agri-land subsidy (neutralization based on commodity taxes) fails to reduce nitrogen usage in agriculture in Croatian data-based model (QEM). Simulation results for budget revenues neutral agri-land subsidy are presented for 1%, 5%, 10% and 20% land extension targets.
Source: author

Figure 6. General equilibrium and environmental effects of command-and-control based agricultural nitrogen reduction measures in Croatia (QEM, substitution allowed)



Note: nitrogen reduction target is shown on horizontal axis. General equilibrium effects are shown on vertical axis and are calculated as the percentage change of GDP, unemployment and agricultural land in new (post-policy implementation) equilibrium (in comparison to initial equilibrium).
Source: author

5 Concluding Remarks, Limitations and Future Research Recommendations

The main objective of this paper was to analyze the effects of selected agricultural nitrogen reduction policies in Croatia, which currently uses command-and-control measures, as outlined in Action Programmes under the EU Nitrates Directive, to deal with agricultural nitrogen pollution. The paper emphasizes the role of initial assumptions in the evaluation of alternative agricultural nitrogen reduction policies, since policy makers deal with several theoretical assumptions violations. With this objective in mind research focuses on the role of available production technologies and labor market imperfections in determination of efficiency, welfare and general equilibrium effects of selected agricultural nitrogen reduction policies. The analysis is carried out within CGE modelling framework using the data for Croatia. While putting the results for Croatia into the perspective of previous similar research findings and environmental taxation theory, the paper acknowledges limitations of the CGE models for evaluation of agri-environmental nitrogen reduction policies (in general and especially in connection to the model developed in this paper). It also emphasizes the methodological and database development needs for future research. Namely, to authors knowledge, agricultural nitrogen reduction policies are still not incorporated in large-scale policy assessment CGE based models. However, it should be noted that some preliminary GTAP based results for the US have been published (LIU et al., 2018). Still, the model seems to be in its experimental phase.

The analysis carried out in this paper led to several conclusions. Firstly, available technology of production is shown to be an important determinant of welfare effects of agri-environmental nitrogen reduction policies in Croatia. Although most of the efficient policies remain efficient regardless of the assumed technology of production, environmental targets are achieved at higher social costs. Secondly, implementation of agricultural nitrogen reduction measures based on taxes (agricultural good and nitrogen taxes) always reduces welfare in Croatia. This finding contradicts usual theoretical environmental taxation conclusions as well as some previous research findings. Thirdly, combined (taxes and subsidies-based) agricultural nitrogen reduction policies are welfare enhancing in Croatia. Although welfare enhancing, these policies are not always successful in reaching nitrogen reduction targets in Croatia, i.e. are not efficient. Namely, the only efficient policy which has the potential to increase welfare in Croatia is the one that combines nitrogen tax and agri-land subsidy. This finding is in line with some previous optimal agri-environmental policy research conclusions. However, this policy becomes inefficient under the complementarity assumption, at least in Croatia. Although this conclusion might not be relevant from macro perspective, as nitrogen fertilizers can be considered substitutable in production process (on average), it might be relevant from the perspective of policy choices for crops with different degree of nitrogen fertilizers substitutability. Finally, and in line with theoretical conclusions as well as some previous research findings, implementation of command-and-control based nitrogen pollution reduction measures (max nitrogen allowed and min agri-land requirements) decreases social welfare in Croatia. However, welfare losses of command-and-control measures in Croatia are lower than taxes-based measures welfare losses (especially in comparison to agricultural good tax, even when its introduction is compensated by labor and income tax reductions). This conclusion is in line with LALLY et al. (2007) findings for Ireland, and supports current command-and-control policy approach to agricultural nitrogen pollution in Croatia. However, up to 17% nitrogen reduction target, it is possible to achieve superior outcomes (in terms of social welfare and macroeconomic effects) by combining agri-land subsidies and nitrogen fertilizers taxes.

By analyzing transmitting mechanisms of each evaluated policy within a model setting in which nitrogen fertilizers are assumed to be substitutable in production process it became obvious that welfare effects depend crucially on adverse labor market response to evaluated measures. On top of that, competitiveness loss hinders taxes-based nitrogen reduction policies potential to induce welfare gains in small open economy like Croatia. The paper also analyzes the role of multifunctionality of agriculture in the determination of welfare effects of evaluated measures. It seems that most of the evaluated (efficient) policies decrease agricultural land (exceptions include the combination of nitrogen tax in agriculture and agri-land subsidy and min agri-land requirements) and therefore reduce possible environmental welfare gains of evaluated policies.

Without the intention to exhaust all open questions and limitations, few shortcomings are worth noting. Evaluation of alternative nitrogen reduction policies carried out in this paper ignores policy implementation, control and administration costs. If those costs differ significantly across policy choices some conclusions might be biased. Approximations in Croatian SAM (due to missing data and uncertainty regarding some of the predetermined parameters for which Croatian data-based estimates don't exist) as well as assumed linearity and one-dimensionality of agricultural nitrogen pollution costs and benefits in environmental goods are also worth reconsidering.

Additionally, the model presented in this paper lacks many potentially important details which are the main advantage of large-scale CGE models used for agri-environmental policy impact assessment. Besides being detailed, these models enable researchers to analyze dynamic and transboundary effects of evaluated policies, which is impossible to analyze within the static model developed in this paper. These effects could be important determinants of efficiency and welfare effects of analyzed policies, especially in the long run. However, as already noted, large-scale policy impact assessment CGE-based models have not been used in the analysis of agricultural nitrogen reduction policies until just recently. This is probably due to nitrogen pollution related data and modelling requirements. Namely, as argued in Section 3, agriculture is a non-point source polluter and the nitrogen use in agriculture is mainly characterized by large heterogeneity and uncertainty. Therefore, the amount of nitrogen emissions largely varies from one farm to another because of many factors (soil quality, crop produced, fertilization and irrigation techniques used, etc.) which lead to a heterogeneous contribution to nitrogen diffuse pollution (see LIU et al. (2018) who developed a grid-resolving model in order to capture the spatial heterogeneity in these relationships). At the disaggregated (micro) level these characteristics may play a crucial role and any research aiming to analyze nitrogen pollution reduction policies at disaggregated level should decompose the whole agricultural sector into different subsectors with relatively similar performance regarding the nitrogen cycle.

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Appendix

Table 1A. Sector (classification of products by activity, 2008) coverage

Index	Products/sectors/goods included
A	Products of agriculture, forestry and fishing, food products, beverages, tobacco products
BC	Mining and quarrying and manufactured products (excluding food products, beverages, tobacco products, from wearing apparel to chemicals and chemical products)
C	Other manufactured products (from basic pharmaceutical products and pharmaceutical preparations to repair and installation services of machinery and equipment)
DG	Electricity, gas, steam and air conditioning; water supply; sewerage, waste management and remediation services, constructions and construction works, wholesale and retail trade services; repair services of motor vehicles and motorcycles
HJ	Transportation and storage services; accommodation and food services; information and communication services
KN	Financial and insurance services; real estate services; professional, scientific and technical services; administrative and support services
OU	Public administration and defense services; compulsory social security services; education services; human health and social work services; arts, entertainment and recreation services; other services; services of households as employers; undifferentiated goods and services produced by households for own use; services provided by extraterritorial organizations and bodies

Table 2A. Croatian economy SAM (bn Croatian kuna, 2010*)

Social accounting matrix		Good							Sector							Factors			Households	Gov	tc	tim	tl	tk	ty	S	RoW	Total
		A	BC	C	DG	HJ	KN	OU	A	BC	C	DG	HJ	KN	OU	L	K	Z										
Good	A[a]								13	1	1	2	3	0	0				62	0						2		84
	BC[b]								6	17	4	8	7	3	2				32	0						0		79
	C[c]								3	2	16	13	6	3	6				23	0						16		88
	DG[d]								5	5	7	17	7	5	6				9	0						46		108
	HJ[e]								2	2	2	6	12	4	5				48	5						4		90
	KN[f]								3	2	3	22	7	15	7				36	6								101
	OU[g]								0	0	0	1	1	0	3				19	59								84
Sector	A	50																									7	57
	BC		28																								16	43
	C			26																							24	51
	DG				122																						13	134
	HJ					76																					15	91
	KN						92																				7	98
	OU							82																			1	83
Factors	L[h]								8	7	11	33	22	18	38													136
	K[i]								13	6	5	20	19	38	8													109
	Z[j]								1	0	0	1	1	5	0													9
Households																136	109	9		42								296
Government																					35	11	23	3	32			104
tc[k]		22	12	10	-16	5	1	1																				35
tim[l]									0	1	1	4	2	2	2													11
tl[m]									1	1	2	6	4	3	6													23
tk[n]									0	0	0	1	1	1	0													3
ty[o]																			32									32
S[p]																			34	-7							42	68
RoW[r]		12	39	52	2	9	8	1																				124
Total		84	79	88	108	90	101	84	57	43	51	134	91	98	83	136	109	9	296	104	35	11	23	3	32	68	124	2142

*latest available data

Note: implied share of land in total factors of production by sector: 6.64% (A), 1.93% (BC), 1.99% (C), 1.80% (DG), 2.55% (HJ), 7.92% (KN – mostly real estate), and 0.57% (OU).

Source: CROATIAN BUREAU OF STATISTICS (2010, 2011a, 2011b, 2015), CROATIAN EMPLOYMENT SERVICE (2011), FINANCIAL AGENCY (2015), MINISTRY OF FINANCE (2010)

Table 3A.a. Empirical CGE model equations (substitution allowed)

$\boldsymbol{C_i}$ $$C_i = \left[(1+tc_i)P_i\mu_i + \alpha_i P_i((1-t_Y)Y - S_H - \textstyle\sum_{i=1}^{7}(1+tc_i)P_i\mu_i)\right]/[(1+tc_i)P_i] \tag{1}$$

$\boldsymbol{S_H}$ $$S_H = mps_H(Y - t_Y Y) \tag{2}$$

$\boldsymbol{KLZB_i}$ $$KLZB_i = aF1_i XD_i \tag{3}$$

$\boldsymbol{XD_i}$ $$XD_i = \left[PKLZB_i KLZB_i + \textstyle\sum_{ni=1}^{6} io_{ni,i}\, XD_i P_{ni}(1+tim_i)\right]/PD_i \tag{4}$$

$\boldsymbol{ZB_i}$ $$ZB_i = \frac{KLZB_i}{aF2_i}\left[\frac{(1-\alpha2_i)}{\alpha2_i}\frac{PKL_i}{PZB_i}\right]^{\alpha2_i} \tag{5}$$

$\boldsymbol{KL_i}$ $$KL_i = \frac{KLZB_i}{aF2_i}\left[\frac{\alpha2_i}{(1-\alpha2_i)}\frac{PZB_i}{PKL_i}\right]^{(1-\alpha2_i)} \tag{6}$$

$\boldsymbol{PKLZB_i}$ $$PKLZB_i = (PKL_i KL_i + PZB_i ZB_i)/KLZB_i \tag{7}$$

$\boldsymbol{B_i}$ $$B_i = \frac{ZB_i}{aF3b_i}\left[\frac{(1-\alpha3_i)}{\alpha3_i}\frac{P_Z(1+sZ_A)}{P_{i=BC}(1+tB_A)}\right]^{\alpha3_i} \tag{8}$$

$\boldsymbol{Z_i}$ $$Z_i = \frac{ZB_i}{aF3b_i}\left[\frac{\alpha3_i}{(1-\alpha3_i)}\frac{P_{i=BC}(1+tB_A)}{P_Z(1+sZ_A)}\right]^{(1-\alpha3_i)} \tag{9}$$

$\boldsymbol{PZB_i}$ $$PZB_i = (P_Z Z(i)(1+sZ_A) + P_{i=BC}B_i(1+tB_A)/ZB_i \tag{10}$$

$\boldsymbol{K_i}$ $$K_i = \left(\frac{KL_i}{aF3a_i}\right)\{(\gamma3^{VA_i})^{\sigma3_{VA_i}}(1+tk_i){P_K}^{-\sigma3_{VA_i}}\left[(\gamma3^{VA_i})^{\sigma3_{VA_i}}(1+tk_i){P_K}^{1-\sigma3_{VA_i}} + (1-\gamma3^{VA_i})^{\sigma3_{VA_i}}(1+ tl_i){P_L}^{1-\sigma3_{VA_i}}\right]^{\frac{\sigma3_{VA_i}}{(1-\sigma3_{VA_i})}}\} \tag{11}$$

$\boldsymbol{L_i}$ $$L_i = \left(\frac{KL_i}{aF3a_i}\right)\{(1-\gamma3^{VA_i})^{\sigma3_{VA_i}}(1+tl_i){P_L}^{-\sigma3_{VA_i}}\left[(\gamma3^{VA_i})^{\sigma3_{VA_i}}(1+tk_i){P_K}^{1-\sigma3_{VA_i}} + (1-\gamma3^{VA_i})^{\sigma3_{VA_i}}(1+ tl_i){P_L}^{1-\sigma3_{VA_i}}\right]^{\frac{\sigma3_{VA_i}}{(1-\sigma3_{VA_i})}}\} \tag{12}$$

$\boldsymbol{PKL_i}$ $$PKL_i = ((1+tl_i)P_L L_i + P_K K_i)/KL_i \tag{13}$$

$\boldsymbol{S}$ $$S = S_H + S_G CPI + S_F ER \tag{14}$$

$\boldsymbol{ID_i}$ $$ID_i = \left[\propto_{I_i}(S)\right]/P_i \tag{15}$$

$\boldsymbol{CG_i}$ $$CG_i = \left[\propto_{CG_i}(TR - TRF - S_G CPI)\right]/P_i \tag{16}$$

$\boldsymbol{TR}$ $$TR = t_Y Y + \textstyle\sum_{i=1}^{7}(tc_i P_i C_i) + tk_i K_i P_K + tl_i L_i P_L + \sum_{i=1}^{7}\sum_{ni=1}^{6} io_{ni,i} XD_i P_{ni} tim_i + P_Z Z_A(1+sZ_A) \tag{17}$$

$\boldsymbol{TRF}$ $$TRF = zP_L U + TRO(CPI) \tag{18}$$

$\boldsymbol{E_i}$ $$E_i = \left(\frac{XD_i}{aT_i}\right)\{(\gamma^{T_i})^{\sigma_{T_i}}{PE_i}^{-\sigma_{T_i}}\left[(\gamma^{T_i})^{\sigma_{T_i}}{PE_i}^{1-\sigma_{T_i}} + (1-\gamma^{T_i})^{\sigma_{T_i}}{PDD_i}^{1-\sigma_{T_i}}\right]^{\frac{\sigma_{T_i}}{(1-\sigma_{T_i})}}\} \tag{19}$$

$\boldsymbol{XDD_i}$ $$XDD_i = \left(\frac{XD_i}{aT_i}\right)\{(1-\gamma^{T_i})^{\sigma_{T_i}}{PDD_i}^{-\sigma_{T_i}}\left[(\gamma^{T_i})^{\sigma_{T_i}}{PE_i}^{1-\sigma_{T_i}} + (1-\gamma^{T_i})^{\sigma_{T_i}}{PDD_i}^{1-\sigma_{T_i}}\right]^{\frac{\sigma_{T_i}}{(1-\sigma_{T_i})}}\} \tag{20}$$

$\boldsymbol{PD_i}$	$PD_i = (PE_iE_i + PDD_iXDD_i)/XD_i$	(21)
$\boldsymbol{M_i}$	$M_i = \left(\frac{X_i}{aA_i}\right)\{(\gamma^{A_i})^{\sigma_{A_i}}PM^{-\sigma_{A_i}}\left[(\gamma^{A_i})^{\sigma_{A_i}}PM_i^{1-\sigma_{A_i}} + (1-\gamma^{A_i})^{\sigma_{A_i}}PDD_i^{1-\sigma_{A_i}}\right]^{\frac{\sigma_{A_i}}{(1-\sigma_{A_i})}}\}$	(22)
$\boldsymbol{X_i}$	$X_i = \frac{aA_iXDD_i}{\{(1-\gamma^{A_i})^{\sigma_{A_i}}PDD_i^{-\sigma_{A_i}}\left[(\gamma^{A_i})^{\sigma_{A_i}}PM_i^{1-\sigma_{A_i}}+(1-\gamma^{A_i})^{\sigma_{A_i}}PDD_i^{1-\sigma_{A_i}}\right]^{\frac{\sigma_{A_i}}{(1-\sigma_{A_i})}}\}}$	(23)
$\boldsymbol{PDD_i}$	$PDD_i = (X_iP_i - PM_iM_i)/XDD_i$	(24)
$\boldsymbol{P_L}$	$\sum_{i=1}^{7} L_i = L_S - U_N$	(25)*
$\boldsymbol{P_K}$	$\sum_{i=1}^{7} K_i = K_S$	(26)*
$\boldsymbol{P_Z}$	$\sum_{i=1}^{7} Z_i = Z_S$	(27)*
$\boldsymbol{P_i}$	$X_i = C_i + ID_i + CG_i + \sum_{ii=1}^{7} io_{i,ii}\,XD_{ii} + \left(\sum_{i=1}^{7} B_i \,\middle|\, i = BC\right)$	(28)*
$\boldsymbol{S_F}$	$S_F = \sum_{i=1}^{3} PWM_{\,i}M_i - \sum_{i=1}^{3} PWE_{\,i}E_i$	(29)
$\boldsymbol{PE_i}$	$PE_i = \overline{PWE_{\,i}}\mathrm{ER}$	(30)
$\boldsymbol{PM_i}$	$PM_i = \overline{PWM_{\,i}}\mathrm{ER}$	(31)
$\boldsymbol{CPI}$	$CPI^1 = \frac{\sum_{i=1}^{7}(1+tc_i^{\,1})PD_i^{\,1}C_i^{\,0}}{\sum_{i=1}^{7}(1+tc_i^{\,0})PD_i^{\,0}C_i^{\,0}}$	(32)
$\boldsymbol{Y}$	$Y = P_L(L_s - U_N) + P_K(K_s) + P_Z(Z_s) + TRF$	(33)
$\boldsymbol{CBUD}$	$CBUD = (1 - t_Y)Y - S_H$	(34)
$\boldsymbol{U_N}$	$[(P_L^{\,1}/CPI^1)/(P_L^{\,0}/CPI^0) - 1] = \mathrm{Phillips}[(U_N^{\,1}/L_s^{\,1})/(U_N^{\,0}/L_s^{\,0}) - 1$	(35)**
$\boldsymbol{E_N}$	$E_N = NOxFACTOR_A\ NOxSHARE_AB_A$	(36)
$\boldsymbol{E_B}$	$E_B = Z_A$	(37)
$\boldsymbol{U}$	$U = \beta_H \prod_{i=1}^{7}(C_i - \mu_i)^{\alpha_i} - \varphi E_N + \theta E_B$	(38)

Notes:

* Equilibrium conditions on the goods market (labor, capital, land): supply of goods (labor, capital, land) - left hand side of Equation (28) (right side of Equations (25), (26), (27)) should be equal to goods demand (labor, capital, land) - right hand side of Equation (28) (left hand side of Equations (25), (26), (27)). The equilibrium in the goods market (labor, capital, land) is achieved at prices P_i (P_L, P_K, P_Z), therefore satisfying Equation (28) ((25), (26), (27)) ensures equilibrium prices in the respective markets.

** The unemployment rate is determined from the wage curve represented by the Equation (35). All the variables and parameters in Equation (35) except the unemployment rate (U_N) are known prior to determination of the unemployment rate. Therefore, the unemployment rate (U_N) is the solution of Equation (35).

*** Variables that indicate the introduction of environmental policies (tax on polluting good (tc_A), tax on the use of nitrogen fertilizers in agriculture ($tX_{BC,A}$), land subsidy (sZ_A) are subsequently introduced in the appropriate equation(s). In QEM, some taxes are included in the model before the implementation of environmental policy. Therefore, when introducing (for example) a tax on polluting good, policy introduction changes the consumption tax (tc_i), but only for the agricultural good (tc_A).

Table 3A.b. Equilibrium conditions and fixed variables

$$\sum_{i=1}^{7} K_i = K_S \quad (39)$$

$$\sum_{ni=1}^{6} L_{ni} + L_A = \overline{L_S} - U_N \quad (40)$$

$$\sum_{i=1}^{7} Z_i = Z_S \quad (41)$$

$$TRO = \overline{TRO} \quad (42)$$

$$S_G = \overline{S_G} \quad (43)$$

$$S_F = \overline{S_F} \quad (44)$$

$$L_A = \overline{L}_A \quad (45)$$

$$P_L = \overline{P_L} \quad (46)$$

List of variables:

i – a set of products/sectors consisting of seven products/ sectors with their associated names/labels and coverage (see Table 1A in Appendix)
$ii = i$
ni – a set of products/sectors other than BC

Endogenous variables:

C_i – consumer demand for products of i-th sector
S_H – consumer savings
$KLZB_i$ – the demand for labor, capital, land and BC sector goods bundle of the i-th producer
XD_i – production of domestic goods of the i-th producer
ZB_i – the demand for land and BC sector goods bundle of the i-th producer
KL_i – the demand for labor and capital bundle of the i-th producer
$PKLZB_i$ – capital, labor, land and BC sector goods bundle prices in sector i
B_i – BC sector good demand of the i-th producer
Z_i – land good demand of the i-th producer
PZB_i – land and BC sector goods bundle prices in sector i
K_i – capital demand of the i-th producer
L_i – labor demand of the i-th producer
PKL_i – capital and labor bundle prices in sector i
S – total savings
ID_i – investment demand in sector i
CG_i – government consumption of i-th good
TR – total tax revenues
TRF – total government transfers to consumers
E_i – exports of i-th sector
XDD_i – domestic goods supply of i-th sector goods in domestic market
PD_i – domestic goods prices of i-th sector goods
M_i – imports of i-th sector
X_i – final/composite good supply of i-th sector goods
PDD_i – price of domestic goods in domestic market
P_K – price of capital
P_Z – price of land
P_i – price of final/composite goods
ER – exchange rate
PE_i – export prices by sectors in domestic currency
PM_i – import prices by sectors in domestic currency
CPI – CPI index
Y – consumer income
$CBUD$ – consumer's budget
U_N – unemployment
E_N – nitrogen fertilizers used in agricultural production (monetary value)
E_B – agricultural land

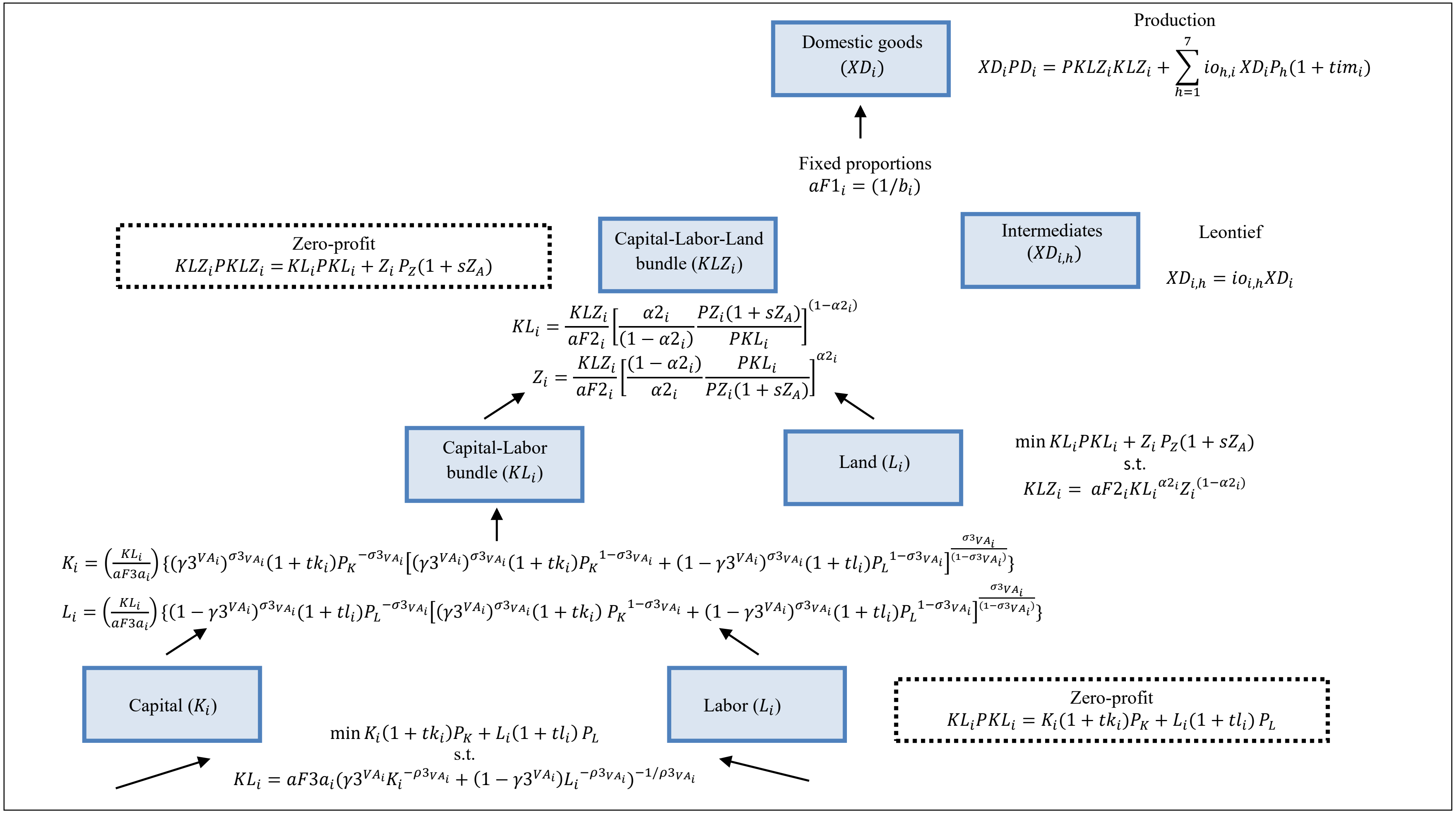
Exogenous variables:

K_S – capital supply
L_S – labor supply
Z_S – land suppy
TRO – other government transfers to consumers
S_G – government savings
S_F – foreign savings
P_L – wage (labor price, numéraire)

Parameters:

tc_i – consumption tax rate in sector i
tk_i – capital tax rate in sector i
tl_i – labor tax rate in sector i
tim_i – intermediates tax rate in sector i
t_Y – income tax rate
sZ_A – agri-land subsidy
tB_A – nitrogen tax (BC sector) in agriculture
mps_H – marginal propensity to save (consumers)
$io_{ni,i}$ – matrix of technical coefficients
z – unemployment benefit (share of wage)
Phillips – Phillips parameter
aA_i – efficiency parameter in Armington CES function (i)
aT_i – shift parameter of CET function (i)
$aF2_i$ – efficiency parameter in labor, capital, land and BC sector goods production function (second nest - KLZB) (i)
$aF3a_i$ – efficiency parameter in labor and capital production function (third nest - KL) (i)
$aF3b_i$ – efficiency parameter in land and BC sector goods production function (i) (third nest - ZB) (i)
α_i – powers of LES utility functions for i-th good (consumers)
$aF1_i$ – shift parameter of the production function (first nest)
$\alpha2_i$ – capital and labor bundle share in the labor, capital, land and BC sector goods bundle in Cobb Douglas production function(i)
$\alpha3_i$ – share of land in the land and BC sector goods bundle (i)
$\propto_{I_i}$ – Cobb Douglas power in investment bank utility function (i)
$\propto_{CG_i}$ – Cobb Douglas power in government utility function (i)
β_H – shift parameter of LES utility function (consumers)
μ_i – subsistence level of consumption of i-th good
σ_{A_i} – elasticity of substitution in Armington CES function (i)
σ_{T_i} – elasticity of transformation in CET function (i)
$\sigma3_i$ – elasticity of substitution of capital and labor in CES production function (i)
γ^{A_i} – distribution parameter of Armington CES function (i)
γ^{T_i} – distribution parameter of CET function (i)
$\gamma3^{VA_i}$ – distribution parameter of capital in CES production function (i)
$NOxFACTOR_A$ – conversion factor represented by GNB per monetary unit of nitrogen fertilizers applied in agricultural sector
$NOxSHARE_A$ – share of chemical industry in agricultural intermediate demand for goods within relevant industry (BC).
φ – marginal cost of nitrogen pollution (consumers)
θ – marginal benefit of agricultural land (consumers)

Figure 1A. Implicit factor and intermediates demand functions and optimal production level (substitution not allowed)



Note: b_i denotes the share of capital-labor input bundle and $(1-b_i)$ the share of intermediates in the domestic output/good, $aF1_i$ is the reciprocal value of capital-labor-land bundle share in the domestic output/good. $aF2_i$is efficiency parameter of Cobb-Douglas function (second level - KLZ_i), $\alpha2_i$ and $(1-\alpha2_i)$ are share parameters of capital-labor bundle and land in Cobb-Douglas function (second level - KLZ_i), $PKL_i$and $PKLZ_i$ are capital-labor bundle and capital-labor-land bundle prices.
Source: author

Table 4A. Predetermined parameters values

Consumers	***Income elasticity***	*A*	*0.63*	**Source:** MUHAMMAD et al. (2011)
		BC	*0.97*	
		C	*1.05*	
		DG	*1.28*	
		HJ	*1.15*	
		KN	*1.07*	
		OU	*1.19*	
	Frisch	*All goods/sectors*	*-1.36*	**Source:** MUHAMMAD et al. (2011) **Explanation:** Calculated as $\frac{\text{income elasticity}}{\text{own price Frisch elasticity}}$.
	Unemployment benefit (share of wage)	*z*	*0.28*	**Source:** CROATIAN BUREAU OF STATISTICS (CBS) (2010); CROATIAN EMPLOYMENT SERVICE (CRS) (2011) **Explanation:** Share of average unemployment benefit in 2010 in average monthly wage in 2010 in Croatia.
Labor market	***Phillips parameter***		*-0.1*	**Source:** upper bound estimate in BLANCHFLOWER (2001)
Producers	***CES - $\sigma 3_{VA_i}$***	*A*	*0.66*	**Source:** HERTEL et al. (2014)
		BC	*1.06*	**Parameters:**
		C	*1.26*	CES – initial elasticity of substitution of labor and capital (CES production function – third nest)
		DG	*1.63*	CET – initial elasticity of transformation in CET function (gives optimal combination of sales on domestic and world markets)
		HJ	*1.58*	Armington – initial elasticity of substitution in Armington function (gives optimal combination of domestic and world product variety).
		KN	*1.26*	**Explanation:** GTAP's sectors are connected to CPA classification. Parameters are calculated as weighted averages of GTAP's parameters according to sub-sectors share in CPA aggregated sector production.
		OU	*1.26*	
	CET - σ_{T_i}	*A*	*-5.6*	
		BC	*-7.1*	
		C	*-7.5*	
		DG	*-4*	
		HJ	*-3.8*	
		KN	*-3.8*	
		OU	*-3.8*	
	Armington- - σ_{A_i}	*A*	*2.8*	
		BC	*3.6*	
		C	*3.75*	
		DG	*2.01*	
		HJ	*1.9*	
		KN	*1.9*	
		OU	*1.9*	

Note: remaining (unknown) parameters values are calibrated.
Source: author