Understanding biomass supply for a territorial biorefinery

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Abstract. This study aims at identifying key contractual provisions that may encourage farmers to introduce some biomass cropping on farm, to support decision-makers when deciding on setting-up a territorial biorefinery. The research uses a principal-agent model to mitigate the inefficiencies of incentive design. Mathematical programming is used for finding a practical solution to the principal-agent problem. Farm types are built via cluster analysis over official data from the last Italian census of agriculture. Agents' marginal costs for adopting biomass cropping are estimated using real world data from Tuscany. Results show that the menu of contracts cannot completely avoid rent extraction by agents, but can reduce the extent of the rent that agents can extract by making a false statement about their cost-profile. First-best conditions allow the principal to have a larger procurement area to meet industry's demand. A risk averse principal would design the menu of contracts to secure the plant with a minimum procurement area to allow continuous and profitable plant operations or, like here, to allow biorefinery's start-up. Few farmers would find it profitable to introduce hemp within their crop mix, given the difference in production costs. Especially, transaction cost turn to be a significant component of principal's profit function, thereby reducing the number of contracts that can potentially be stipulated. Larger farmer types seem to benefit more from contract participation, in terms of increased profit, by taking advantage of economies of scale and perhaps investing in additional facilities to pre-treat biomass, which would raise products' value added at the farm gate.

Keywords: incentive design, principal-agent, procurement contract, biorefinery, hemp

Introduction

Biorefineries are central in EU's strategy towards 2020. However, setting up a biorefinery involves making an irreversible investment, as well as high start-up and management costs. Then, investors need to secure the plant with enough biomass supply to guarantee continuous operations and stable output. This study aims at identifying key contractual provisions that may encourage farmers to introduce some biomass cropping on farm, to support decision-makers when deciding on setting-up a territorial biorefinery. Those provisions are meant to be the elements of a menu of contracts (Moxey et al.,1999) that are attractive for arable farmers within 70 km from the prospected biorefinery's headquarter (Italian law DM 18-12-2008). Biorefinery operators are willing to stipulate biomass procurement contracts with farmers, for secure continuous and optimal operations. The contract provides farmers with a fixed price for a given number of years. Contract agreements are recognised risk management tools (MacDonald et al., 2004). The case study Tuscany, a region that features large enough arable farming systems to sustain a biorefinery, via the introduction of a multi-purpose industrial crop, such as hemp. Hemp can be included in traditional rotations with cereal and fodder crops, thus offering farmers the opportunity to diversify their crop mix, raise farming profitability, and reduce uncertainty. The present research uses a principal-agent model to mitigate the inefficiencies of incentive design. Mathematical programming is used for finding a practical solution to the principal-agent problem (Viaggi et al., 2009). Farm types are built via cluster analysis over official data from the last Italian census of agriculture (2010). Agents' marginal costs for adopting biomass cropping are estimated using real world data, originating from an ongoing research project funded by the Rural Development Program of Tuscany 2014-2020. The project aims at creating a farm-to-gate supply chain for hemp-based products in Tuscany, including the construction of a territorial biorefinery.

Methodology

The investment in a biorefinery is irreversible, with high initial costs. Then, it is critical for the investor to have biomass supply guaranteed for a long enough period. In practice, this implies stipulating biomass procurement contracts with farmers to create stable relations and ensure biorefinery's profitability against exogenous risk (Wu, 2014). An underlying condition for locating a territorial biorefinery is defining a plausible biomass supply area, hosting enough arable farmers that might be interested in subscribing a contract. The contract should incentivise farmers to introduce an industrial crop on farm to meet biorefinery's demand. In turn, the biorefinery would be guaranteed with continuous and minimum-cost plant operations. In economics, creating such a contract is a principal-agent problem (Laffont and Tirole, 1993), where biorefinery's operator, i.e. biomass end-user, is the principal and farmers, i.e. biomass producers, are the agents (Alexander et al., 2012). The solution of the principal-agent problem would help the principal to identify the incentive mechanism that maximises farmers' participation into the contract while minimizing principal's costs (Bartolini et al., 2005). Based on bio-based-product demand by the downstream industry, bio-based supply chains have evolved into hybrid systems where biomass processors closely cooperate with heterogeneous farmers through contracting, rather than as direct owners or operators of biomass farms (Endres et al., 2013). Contractual agreements involve the principal delegating biomass cropping to as set of agents over a geographical area, to satisfy plant processing constraints. Task delegation may determine information asymmetries due to agents' hidden information or hidden actions. In information economics, information asymmetries between the contracting parties are considered explicitly (Scoppa and Nicita, 2005). Hidden information increases the costs associated with the search of optimal contracting partners and their preferences, thus underling adverse selection problems (Wu and Babcock 1996; MacDonald et al., 2004). Hidden action implies the rise of monitoring costs to ensure the execution of contract terms by agents, which causes moral hazard problems (Fraser, 2002; Ferraro, 2008). Here, we focus on the former to try and mitigate inefficiency throughout the supply chain.

The principal-agent model

Adverse selection problems arise typically during contract negotiation, as the principal offers a contract to farmers of whom she cannot observe preferences, notably towards risk, opportunity cost, or minimum demand for compensation (Salanié, 2005). In fact, farmers have an informational advantage, notably with respect to the pedo-climatic conditions of their farm and in terms of agronomic knowledge (Alexander et al, 2012). For one, the principal might not be able to calibrate incentive levels on agent characteristics and costs. Then, information advantage allows agents to get higher payments than the minimum that would be necessary for them to accept the contract (Ferraro, 2008). Farmers may make a strategic use of the information rents they extract from the principal. For example, low-opportunity-cost agents can claim to be high-opportunity-cost ones in negotiation for benefiting from the additional rents necessary to attract high-cost farmers, thereby raising principal's input supply costs (Endres et al., 2013). This has obvious implications when trying and planning cost-effective biomass supply for a biorefinery. Isolation strategies, including rationing, screening, signaling, and auctioning, are available from the economic literature on complete contracts, to induce agents to reveal their true cost profile, while preventing the principal from paying them excessive information rents (Salanié, 2005). Screening, i.e. matching agents' profiles with a menu of targeted contracts, is perhaps the more complicated (Arguedas and van Soest, 2011) but more efficient strategy to address adverse selection (Endres et al., 2013). In line with the revelation principle (Laffont and Tirole, 1993), the rationale behind the design of such a menu of contracts is allowing agents' participation (incentive rationality constraint), while satisfying the incentive compatibility constraint, so that each agent profile cannot be better off by choosing a contract designed for another profile (Ferraro, 2008). The screening contract would then involve different levels of payment over different cultivated areas for different agents' profiles. Here, agents' profiles are approximated by representative farm types in the case study area.

We assume that the principal operates towards the maximization of biorefinery returns (*Z*), subject to a minimum cultivated area constraint to ensure a minimum threshold of feedstock area (Eq. 1). Let *L* be the biomass supply area that allows optimal biorefinery operations and *V* the sale price of biorefinery outputs. Let *n*, the number of heterogeneous farm types involved into biomass production, ρ biomass yield per ha UAA cultivated with biomass in terms of biorefinery output, Φ the number of stipulated contracts, and *fc* and *vc* respectively fixed and variable transaction costs. Then, the objective function (*Z*) is as follows (Equation 1):

$$MaxZ = V \cdot \rho \cdot x_n - (b^* \cdot x_n + fc \cdot \Phi + vc \cdot x_n) \qquad (1)$$

s.t.

$$\sum_{n=0}^{N} x_n \geq L$$

Each agent would allocate a share of utilised agricultural area (UAA), *x*, to biomass cropping in exchange of a payment, *b*, that must cover at least the returns of the next best alternative to biomass cropping (i.e. traditional crop). Let *X* be each agent's UAA, $\Pi_0(X)$ the profit associated with the traditional crop, with $\Pi_0'(.) > 0$ and $\Pi_0''(.) < 0$, then $\Pi_1(X - x)$ is the profit associated with biomass cropping, which is a decreasing function of the share of the agricultural area *x* that the farmer allocates to biomass. If farmers do not cultivate biomass to the measure (i.e. x=0), the $\Pi_1(X)$ correspond to the conventional profit $\Pi_0 = \Pi_0(X) = \Pi_1(X - 0) = \Pi_1(X)$. the profit generates by biomass crop, with both $\Pi'(.) > 0$ and $\Pi''(.) < 0$. Assuming that biomass returns differ from the returns of the traditional crop, the difference between the two profits θ=$\Pi_0(x)$ - $\Pi_1(X - x)$ is an opportunity cost for the farmer (Viaggi et al., 2008). To address the adverse selection mechanism caused by hidden information about the costs of different agent profiles (Laffont and Martimort, 2002), contract implementability (first best) and incentive compatibility (second best) conditions must hold throughout the model. Let us assume that three agent profiles $\underline{\theta}$, $\bar{\theta}$, $\bar{\bar{\theta}}$, exist that differ just for marginal production costs, such that the following relationship holds among marginal production costs on farm: $\underline{\theta} > \bar{\theta} > \bar{\bar{\theta}}$. The difference in marginal production costs mirrors that in marginal opportunity costs, such that the following relationship exists among the marginal opportunity costs of the three agent profiles $\underline{\Delta\pi} > \overline{\Delta\pi} > \overline{\overline{\Delta\pi}}$. Then, $\underline{x}, \bar{x}, \bar{\bar{x}}$ are the shares of *X* that each agent profile would respectively shift from crop *k* to crop *b* in case of an optimal contractual agreement, to have their utility (U) maximized. Maximal U occurs when marginal production costs equal optimal unitary area-based payment (p^*) per agent profile. The contract is implementable if it allows all agent profiles to increase their utility at the same time (system of Equations 2 through 4):

$$\underline{U} = \underline{p}^* \cdot \underline{x} - \underline{\theta}' \cdot \underline{x} \geq 0 \tag{2}$$

$$\bar{U} = \bar{p}^* \cdot \bar{x} - \bar{\theta}' \cdot \bar{x} \geq 0 \tag{3}$$

$$\bar{\bar{U}} = \bar{\bar{p}}^* \cdot \bar{\bar{x}} - \bar{\bar{\theta}}' \cdot \bar{\bar{x}} \geq 0 \tag{4}$$

Provided that low-cost agents ($\bar{\bar{\theta}}$) would try and portray themselves as medium ($\bar{\theta}$) or high-cost ($\underline{\theta}$) agents to extract information rents, the menu of contracts proposed by the principal should aim at minimizing those information rents while encouraging agents to declare their true cost profile. Agents will only do that if the contract provide them with a better deal. This implies contract compliance with the so called local and global incentive compatibility constraints (Laffont and Martimort, 2002). To satisfy local incentive compatibility, the utility U of each agent profile should exceed that of the closest cost profile – e.g., U of medium-cost agent should exceed that of both high and low-cost agents – (Equations 5 through 8):

$$\underline{p}^* \cdot \underline{x} - \underline{\theta}' \cdot \underline{x} \geq \bar{p}* \cdot \bar{x} - \bar{\theta}' \cdot \bar{x} + \Delta\underline{\theta}' \cdot \bar{x} \tag{5}$$

$$\bar{p}^* \cdot \bar{x} - \bar{\theta}' \cdot \bar{x} \geq \bar{\bar{p}}^* \cdot \bar{\bar{x}} - \bar{\bar{\theta}}' \cdot \bar{\bar{x}} - \Delta\bar{\theta}' \cdot \bar{\bar{x}} \tag{6}$$

$$\bar{p}^* \cdot \bar{x} - \bar{\theta}' \cdot \bar{x} \geq \underline{p}^* \cdot \underline{x} - \underline{\theta}' \cdot \underline{x} - \Delta\underline{\theta}' \cdot \underline{x} \tag{7}$$

$$\bar{\bar{p}}^* \cdot \bar{\bar{x}} - \bar{\bar{\theta}}' \cdot \bar{\bar{x}} \geq \bar{b}^* \cdot \bar{x} - \bar{\theta}' \cdot \bar{x} - \Delta' \bar{\theta} \cdot \bar{x} \tag{8}$$

Instead, global incentive compatibility involves the utility of each agent profile exceeding that of the farther cost-profile, i.e. U of the high-cost profile should exceed that of the low-cost profile and vice versa (Equations 9 and 10):

$$\underline{p}^* \cdot \underline{x} - \underline{\theta}' \cdot \underline{x} \geq \bar{\bar{p}}^* \cdot \bar{\bar{x}} - \bar{\bar{\theta}}' \cdot \bar{\bar{x}} + 2\Delta\bar{\bar{\theta}}' \cdot \bar{\bar{x}} \tag{9}$$

$$\bar{\bar{p}}^* \cdot \bar{\bar{x}} - \bar{\bar{\theta}}' \cdot \bar{\bar{x}} \geq \underline{p}^* \cdot \underline{x} - \underline{\theta}' \cdot \underline{x} - 2\Delta\underline{\theta}' \cdot \underline{x} \tag{10}$$

When agents' U satisfies the global incentive compatibility, Equations 6, 8, 9, 10 reduce to Equation 11 (Bolton and Dewatripont, 2004):

$$\underline{p}^* \cdot \underline{x} - \underline{\theta}' \cdot \underline{x} \geq \bar{\bar{p}}^* \cdot \bar{\bar{x}} - \Delta\theta' \left(\bar{x} + \bar{\bar{x}} \right) \tag{11}$$

A last and sufficient condition for the contract to be implementable is the single-crossing, or Spence-Mirrlees, condition. Contract mechanism must allow the marginal rate of substitution of crop k with crop b to increase as agents' costs decrease. So, U should be a monotonical function, such that $\bar{\bar{x}} > \bar{x} > \underline{x}$.

Estimation of agent's costs

The empirical research uses representative farm types, created via cluster analysis. Data are from the last Italian census of agriculture and refer to a NUTS 3 region, i.e. the administrative province of Pisa, in Tuscany. The clustering procedure returned 13 representative types of arable farms. Industrial hemp is the biomass crop (crop *b*) under study. We estimate hemp production costs for the *n*-th farm via gross margin (*GM*) maximization, subject to input (*h*) constraints, namely land availability and technology. Let gm_j be the gross margin per unit X cultivated with hemp (*j*), δ the smallest possible share of X cultivated with hemp that allows biorefinery's operations, βh_n the availability of input *h* to the *n*-th farm, and αh_j the smallest possible quantity of input *h* that allows the cultivation of one unit X with hemp. Then the objective function (*W*) is to maximize GM as follows (Equation 12):

$$MaxW = \sum_j \sum_i gm_j \cdot x_i \tag{12}$$

s.t.

$$\sum_j \sum_i \sum_n \alpha h_j \cdot x_i \leq \beta h_n$$

$$\sum_n x_n \geq \delta \quad \forall \delta \in \Re : \delta > 0$$

Resulting agents' costs are used for identifying farm types' compliance with first and second best contractual conditions in case of two different principal's requirements in terms of minimum procurement area (*L*). We then constructed agents' cost function depending on the share of X allocated to hemp cultivation (*x*) via interpolation.

Results

This paragraph starts by depicting the cost-function; then it reports about utilised agricultural areas that each farm type is willing to allocate to hemp cropping, price per unit area that would allow each farm type to participate into the contract, and potential contract number per farm type. Figure 1 shows the relationship between product price at the biorefinery gate and area allocated to biomass cropping for the first and second-best models, under the assumptions of no transaction costs (*fc* = *vc* = 0) and no minimum biomass procurement area (L) to meet the biorefinery demand (Figure 1).

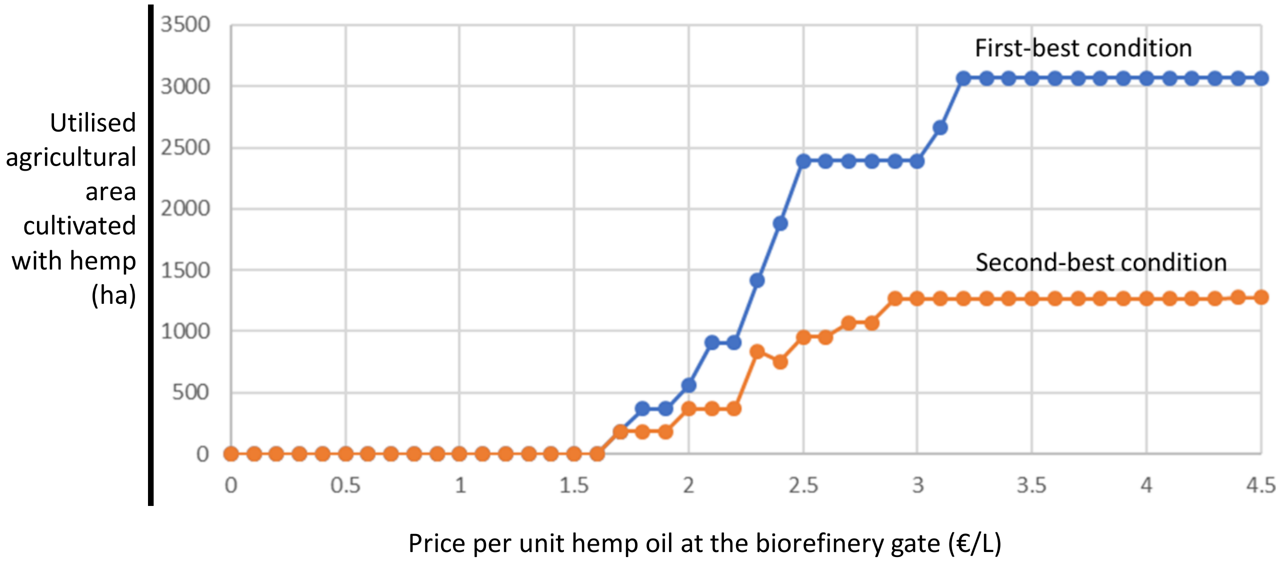

Figure 1. *Production-cost curves for hemp in case of f*irst (blue) and second (red) best *conditions. The cost function assumes no t*ransaction costs and no minimum cultivated area. Source: Authors' own elaboration.

The biorefinery processes hemp biomass to deliver different products for the bio-based industry. Type and grade of biorefinery's products depend on the industrial application and, in turn, on the end use of the marketed industrial product, which ultimately affects different industries' willingness to pay for biorefinery's products. For example, the automotive sector demands fibre-based products of variable grade to be embedded into interior panels and has a significantly lower willingness to pay than the cosmetics sector, which demands high grade oil for producing skin care products. Being seeds the value added primary product, hemp cultivation would presumably rely on double purpose cultivars, with seed harvest index of above 10 (Faux et al., 2013). Then, industry's willingness to pay should be higher for oil based that for fibre-based products. This may hinder biorefinery's ability to find a one-size fits all area-based payment for farmers. Results a very sensitive to price changes, especially in the range €1.5-3/L end-product, where the utilised agricultural area converted to hemp cropping steeply increases from 90 to 3000 ha. The area under contract differs between first and second-best conditions, due to existing information asymmetry between the principal and the agents. Assuming that the principal has access to information about farmers' production costs, she can use that information to design a menu of contract that matches the features of different cost-profile farmers, thereby reducing farmers' information rent and attracting more farmers over a wider area. Instead, assuming that information about farmers' production costs is hidden to the principal, the agents have an advantage, which they can use to extract information rents by participating to a contract tailored for different cost-profile farmers. Rent extraction by agents reduces the area and the number of farms involved into the contractual agreement. Under this condition, the principal would design a menu of contract to screen farms types and reduce their information rents. The menu of contracts cannot completely avoid rent extraction by agents, but can reduce the extent of the rent that agents can extract by making a false statement about their cost-profile. The difference between cost curves under first and second-best conditions graphically exemplify that observation. First-best conditions allow the principal to have a larger procurement area to meet industry's demand. A risk averse principal would design the menu of contracts to secure the plant with a minimum procurement area to allow continuous and profitable plant operations or, like here, to allow biorefinery's start-up. This way the principal tries and reduce investment-risk. Contract design would then involve considering the transaction costs that are expected to arise from the negotiation. We now assume that agents (farm types) can choose to allocate a minimum (δ) of 500 ha or 1000 ha UAA to biomass cropping. We also assume the existence of three levels of transaction costs, i.e. no (€0/ha), low (€25/ha), and high (50/ha) costs. Tables 1-3 display respectively the area under contract, the associated area-based payment, and the number of subscribed contracts per farm type.

Table 1. First (fb) and second best (sb) utilised agricultural area (ha) that agents are willing to cultivate with hemp, when they are proposed with a menu of contracts specifying minimum cultivated areas (L), and assuming no (€0/ha), low (€25/ha), or high (€50/ha) transaction costs (TC). Source: Authors' own elaboration.

Farm type	Model	L≥ 500 ha			L≥ 1000 ha		
		noTC	*lowTC*	*highTCa*	*noTC*	*lowTC*	*highTCa*
1	fb	0	0	0	0	0	0
	sb	0	0	0	5	5	0
2	fb	90	90	90	90	90	90
	sb	90	90	90	90	90	90
3	fb	0	0	0	0	0	0
	sb	0	0	0	7	7	0
4	fb	0	0	0	212	212	212
	sb	2.37	3.45	2.46	7	7	7
5	fb	0	0	0	68	68	68
	sb	2.37	3.45	2.46	7	7	7
6	fb	0	0	0	0	0	0
	sb	0	0	0	5	5	0
7	fb	47.4	47.4	47.4	47.4	47.4	47.4
	sb	47.4	47.4	47.4	47.4	47.4	47.4

8	fb	0	0	0	0	0	0
	sb	0	0	0	2.71	2.71	7
9	fb	0	0	0	0	0	0
	sb	0	0	0	2.07	2.07	0
10	fb	0	0	0	0	0	0
	sb	0	0	0	5	8	15
11	fb	0	0	0	6.6	2.15	6.6
	sb	2.37	3.45	2.46	7	7	7
12	fb	65.2	65.2	65.2	95	95	95
	sb	18	24	0	95	95	95
13	fb	0	0	0	0	0	0
	sb	0	0	0	2.07	2.07	0

Table 2. First (fb) and second (sb) best price per unit area (€/ha) that would encourage agents' participation into the contract, given minimum cultivated area (L) requirements, and assuming no (€0/ha), low (€25/ha), or high (€50/ha) transaction costs (TC). Source: Authors' own elaboration.

Farm type	**Model**	**L≥ 500 ha**			**L≥ 1000 ha**		
		noTC	***lowTC***	***noTC***	***lowTC***	***noTC***	***lowTC***
1	fb	1264.3	980	980	980	980	980
	sb	1264.3	1264.3	1264.3	1106.17	1264.3	1106.17
2	fb	657.7	657.7	657.7	657.7	657.7	657.7
	sb	690.3	692.49	690.48	689.66	754.81	689.66
3	fb	1264.3	974.58	974.58	974.58	974.58	974.58
	sb	1264.3	1264.3	1264.3	1068.57	1264.3	1068.57
4	fb	1264.3	831.1	831.1	831.1	831.1	831.1
	sb	892.67	892.66	892.67	1068.57	842.09	1068.57
5	fb	816.97	816.97	816.97	816.97	816.97	816.97
	sb	892.67	892.66	892.67	1068.57	842.09	1068.57
6	fb	1132.54	994.16	994.16	994.16	994.16	994.16
	sb	1264.3	1264.3	1264.3	1106.17	1264.3	1106.17
7	fb	710.48	710.48	710.48	710.48	710.48	710.48
	sb	719.59	723.76	719.94	1068.57	842.09	1068.57
8	fb	906.33	906.33	906.33	906.33	906.33	906.33
	sb	1264.3	1264.3	1264.3	1068.57	925.8	1068.57
9	fb	1273.3	1211.9	1211.9	1211.9	1211.9	1211.9
	sb	1264.3	1264.3	1264.3	1264.3	1264.3	1264.3
10	fb	925.79	925.79	925.79	925.79	925.79	925.79
	sb	1264.3	1264.3	1264.3	1068.57	925.8	1068.57
11	fb	892.65	892.65	892.65	892.65	892.65	892.65
	sb	892.67	892.66	892.67	1068.57	905.5	1068.57
12	fb	787.81	787.81	787.81	787.81	787.81	787.81
	sb	892.67	892.66	892.67	1068.57	842.09	1068.57
13	fb	1264.3	1264.3	1264.3	1264.3	1264.3	1264.3
	sb	1264.3	1264.3	1264.3	1264.3	1264.3	1264.3

Table 3. Estimated number of subscribed contracts per farm type under first (fb) and second best (sb) conditions, in case of two different minimum cultivated areas (L), and assuming no (€0/ha), low (€25/ha), or high (€50/ha) transaction costs (TC). Source: Authors' own elaboration.

Farm type	Model	L≥ 500 ha			L≥ 1000 ha		
		noTC	*lowTC*	*noTC*	*lowTC*	*noTC*	*lowTC*
1	fb	0	0	0	0	0	0
	sb	0	0	0	20	20	0
2	fb	2	2	2	2	2	2
	sb	2	2	2	2	2	2
3	fb	0	0	0	0	0	0
	sb	0	0	0	5	5	0
4	fb	0	0	0	1	1	1
	sb	1	0	1	1	1	1
5	fb	0	0	0	2	2	2
	sb	2	2	2	2	2	2
6	fb	0	0	0	0	0	0
	sb	0	0	0	15	15	0
7	fb	4	4	4	4	4	4
	sb	4	4	4	4	4	4
8	fb	0	0	0	0	0	0
	sb	0	0	0	1	1	1
9	fb	0	0	0	0	0	0
	sb	0	0	0	1	1	0
10	fb	0	0	0	0	0	0
	sb	0	0	0	15	15	15
11	fb	0	0	0	14	14	43
	sb	34	34	50	50	50	50
12	fb	2	2	2	2	2	2
	sb	2	2	0	2	2	2
13	fb	0	0	0	0	0	0
	sb	0	0	0	40	40	0

Results show that just few farmers would find it profitable to introduce hemp within their crop mix, given the difference in production costs. Especially, transaction cost turn to be a significant component of principal's profit function, thereby reducing the number of contracts that can potentially be stipulated. Larger farmer types seem to benefit more from contract participation, in terms of increased profit, by taking advantage of economies of scale and perhaps investing in additional facilities to pre-treat biomass, which would raise products' value added at the farm gate. Pre-treatment facilities would greatly improve seed loss and nutritional quality and carry out fibre first-step processing that facilitate the second step at the biorefinery level.

Conclusions

Preliminary results suggest that the case study offers the concrete possibility to stipulate contracts with enough farmers to allow the creation of a biomass procurement area that can sustain a territorial biorefinery. Contract subscribers are those who manage the largest arable farms of the case study area, that miss steep mountains, and offer ease of access to means of transport (existing infrastructures). Asymmetric information is a relevant source of inefficiency. The design of contract mechanisms to extract private information from agents may mitigate that inefficiency. This paper presents the results of the application of complete contract theory to the bio-based sector, a promising field of research. The empirical analysis focuses on a case study in Tuscany and uses real world and official data from 13 arable farm types (agents). The impact of transaction costs on contract subscription is assessed for three exemplifying cost profiles (no costs, current costs, high costs). This improves the model by allowing to evaluate an additional source of market failure (transaction costs). Transaction costs turn to be play a marked role in determining biorefinery's profitability, thereby affecting mechanism design by the principal.

Bibliography

Alexander, C., Ivanic, R., Rosch, S., Tyner, W., Wu, S. Y., & Yoder, J. R. (2012). Contract theory and implications for perennial energy crop contracting. *Energy Economics*, *34*(4), 970-979.

Arguedas, C., & van Soest, D. P. (2011). Optimal conservation programs, asymmetric information and the role of fixed costs. *Environmental and Resource Economics*, *50*(2), 305.

Bartolini, F., Gallerani, V., Raggi, M., & Viaggi, D. (2005). Contract design and targeting for the production of public goods in agriculture: the impact of the 2003 CAP reform. In *International EAAE Congress, August 23-27, 2005, Copenhagen, Denmark* (No. 24559).

Bolton, P., & Dewatripont, M. (2004). *Contract Theory*. MIT Press.

Endres, J. M., Endres, A. B., & Stoller, J. J. (2013). Building bio-based supply chains: Theoretical perspectives on innovative contract design. *UCLA J. Envtl. L. & Pol'y*, *31*, 72.

Faux, A. M., Draye, X., Lambert, R., d'Andrimont, R., Raulier, P., & Bertin, P. (2013). The relationship of stem and seed yields to flowering phenology and sex expression in monoecious hemp (Cannabis sativa L.). *European journal of agronomy*, *47*, 11-22.

Ferraro, P. J. (2008). Asymmetric information and contract design for payments for environmental services. *Ecological economics*, *65*(4), 810-821.

Fraser, R. (2002). Moral hazard and risk management in agri-environmental policy. Journal of Agricultural Economics 53(3), 475–487.

Laffont, J. J. and D. Martimort (2002) *The Theory of Incentives: The Principal-Agent Model*. Princeton University Press.

Laffont, J. J., & Tirole, J. (1993). *A theory of incentives in procurement and regulation*. MIT press.

Lopolito, A., Nardone, G., Prosperi, M., Sisto, R., & Stasi, A. (2011). Modeling the bio-refinery industry in rural areas: A participatory approach for policy options comparison. *Ecological Economics*, *72*, 18-27.

MacDonald, J. M., Perry, J., Ahearn, M. C., Banker, D., Chambers, W., Dimitri, C., Key, N., Nelson, K., & Southard, L. W. (2004). *Contracts, markets, and prices: Organizing the production and use of agricultural commodities. Agricultural Economic Report No. (AER-837).* U.S. Department of Agriculture – Economic Research Service: USA. Available from: https://www.ers.usda.gov/webdocs/publications/41702/14700_aer837_1_.pdf?v=41061. Last retrieved June 6th, 2017.

Moxey, A., White, B., & Ozanne, A. (1999). Efficient Contract Design for Agri-Environment Policy. *Journal of agricultural economics*, *50*(2), 187-202.

Salanié, B. (2005). *The economics of contracts: a primer*. MIT press.

Schneider, M. P. (2006). Plant-oil-based lubricants and hydraulic fluids. *Journal of the Science of Food and Agriculture*, *86*(12), 1769-1780.

Scoppa, V., & Nicita, A. (2005). Economia dei contratti. *Roma, Carocci editore*.

Viaggi, D., Bartolini, F., & Raggi, M. (2009). Combining linear programming and principal–agent models: An example from environmental regulation in agriculture. *Environmental Modelling & Software,* 24(6), 703-710.

Wellisch, M., Jungmeier, G., Karbowski, A., Patel, M. K., & Rogulska, M. (2010). Biorefinery systems–potential contributors to sustainable innovation. *Biofuels, bioproducts and biorefining*, *4*(3), 275-286.

Wu, S. Y. (2014). Adapting contract theory to fit contract farming. *American Journal of Agricultural Economics*, 96(5), 1241-1256.

Wu, J., & Babcock, B. A. (1996). Contract design for the purchase of environmental goods from agriculture. *American Journal of Agricultural Economics*, *78*(4), 935-945.