Government Interventions in Promoting Sustainable Practices in Agriculture

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December 2016

Sustainable practices in agriculture such as organic farming have attracted immense attention in recent decades due to the increase in environmental and health concerns. Government support is often used to incentivize producers to convert to sustainable practices. We investigate the effectiveness of government interventions including tax, subsidy and hybrid policies in terms of their impact on sustainable practice adoption, producers’ profits, consumer surplus, and return on government spending using a setting in which producers with traditional and sustainable production options serve consumers that have a high value for sustainable production. Our results indicate that while tax policies encourage sustainable production adoption, the social welfare is reduced. Subsidy policies outperform hybrid policies in achieving higher social welfare but the converse is true for achieving a higher adoption rate. We find that zero-expenditure policies that use the taxes imposed on non-adopters to fund the subsidies provided to adopters result in a decline in social welfare. We also investigate the case with financially constrained producers that cannot afford the conversion to sustainable practices without the support from the government and find that zero-expenditure policies may be beneficial for the social welfare in this case. Finally, we calibrate our model using data on conventional and organic egg production in Denmark and make recommendations on policy choices in order to achieve the target adoption rate set by the Danish government.

Key words: government intervention; subsidies; agricultural supply chains; sustainable agriculture; organic farming

1. Introduction

Agriculture, contributing to 3.9% of global gross domestic product, is an important sector around the world (The World Bank 2016). Due to numerous environmental and health concerns, sustainable agricultural practices such as organic farming have attracted immense attention in recent decades. According to the UN (2013), a shift from conventional, monoculture-based, chemical-input-dependent agricultural production systems to sustainable, regenerative production practices is needed in order to protect the world’s natural resources, mitigate climate change and meet the
increasing global demand for food in a sustainable manner. Since conventional farming methods cause soil degradation, limiting its ability to hold CO$_2$, regenerative methods are needed to recover degraded soils, making organic farming essential in preventing global warming (Hickel 2016). Moreover, severe health consequences of chemical inputs used in conventional agriculture (3 million cases of acute pesticide poisoning and 300,000 deaths annually due to the use of agrochemicals) can be avoided by the transition to organic agriculture (CBTF 2008).

Organic products are usually associated with price premiums, making it desirable from the producers’ perspective to engage in organic production. However, there are in fact important barriers that prevent a majority of farmers from adopting organic practices. First, despite the cost savings due to the elimination of chemical inputs such as fertilizers, pesticides etc., organic farming, being much more labor intensive than conventional production methods, generally results in higher production costs. Secondly, production yields tend to be lower in organic farming during the first few years of conversion. Lack of knowledge of the best practices such as the use of manure, crop rotation, methods to prevent pests and weeds contributes to yield losses encountered during the transition period, constituting a financial barrier for producers that intend to adopt organic farming. It is found that farms that intensively use agrochemicals in conventional production are likely to experience yield losses estimated between 5% and 20% in the initial years (Rundgren 2006). The trade off between higher expected prices and the costly transition period with lower yields shapes a producer’s decision of whether to adopt organic practices.

Given that it might not always be financially attractive for producers to convert to sustainable practices, the policy maker can play an important role in promoting these practices for various reasons including but not limited to improvement in the health conditions of the farmers and the consumers, improvement in soil quality, protecting biodiversity, preventing surface water contamination and meeting increasing domestic and international demand for organic produce (CBTF 2008). Denmark constitutes a good example of successful promotion of organic farming via government interventions. The Danish organic market is well-established with a market share of 7.6%, highest in the world (Willer and Schaack 2016). With the goal of reducing the use of pesticides and protecting the country’s water resources, organic farming was first regulated in 1987 with the adoption of the Organic Farming Act and permanent organic subsidies were introduced in 1994 (Daugbjerg and Sonderskov 2012, CBTF 2008).

There are various means the policy maker can implement in order to support the transition to organic agriculture. For instance, most countries have tax exemptions or subsidies available for agricultural inputs such as pesticides, synthetic fertilizers or GMO seeds, which creates a disadvantage against organic production (CBTF 2008). Thus, one type of policy to promote organic agriculture entails eliminating subsidies on conventional inputs or taxing them, which increases
the cost of conventional agriculture, and thus incentivizes farmers to convert to organic farming. Another way to promote organic production is to implement subsidies that encourage the use of sustainable practices. Environmental subsidies and area payments are examples of such government support. Moreover, the organic certification process is often costly and producers cannot benefit from the price premiums during the pre-certification transition period, providing opportunity for possible government support on the certification process in order to ease the financial burden on producers during the transition phase. The Danish government’s objective of doubling the organically cultivated area by 2020 requires the need for policy support. Over a 5-year commitment period, annual subsidies that amount to €140 per hectare are provided to farmers during the first two years of conversion as well as €13 per hectare for the next three years (Willer et al. 2014). Moreover, certification is undertaken by the government and it is free for farmers. In addition to subsidizing the organic sector, the Danish government levies taxes on chemicals inputs such as fertilizers and pesticides in order to reduce the use of conventional farming.

Given that sustainable practices in agriculture are becoming increasingly important for the aforementioned environmental and health reasons, and governments are allocating substantial resources to promote these practices, it is important to understand the effectiveness of policies in terms of their impact on sustainable practice adoption, producers and also consumers. Thus, in this paper we investigate the following research questions.

1. How do government interventions such as taxing the conventional practice, subsidizing the sustainable practice or incorporating both affect the adoption of the sustainable practice, producers’ incomes and the consumer surplus?
2. Which intervention type is more effective? How do the policy characteristics impact benefits to different stakeholders?
3. What is the net effect of interventions after accounting for government spending?

We investigate the effectiveness of government interventions using a setting in which producers with traditional and sustainable production options serve consumers that have a high value for sustainable production. Each producer is small and acts as a price-taker. Production is subject to random yield for both practices and once the yields are realized, the prices are determined at the market clearing level. We study a two period model where the first period represents the transition phase to the sustainable practice and the second period represents the long-run steady state of the system. Producers choose whether or not to convert to the sustainable practice in period 1 while taking future benefits into account. Our model incorporates the learning-by-doing aspect of sustainable practice adoption. In practice, farmers are likely to suffer from losses due to pest attacks and weeds in the initial years of converting to organic farming since the use of agrochemicals is prohibited. Practices such as crop rotation and intercropping are applied to replace
the use of chemical pesticides and manures and compost are used instead of chemical fertilizers (CBTF 2008). However, farmers often lack the knowledge of such organic management methods, which makes the transition period more challenging (Wynen 2003). As the farmer gains experience and learns these methods and soil fertility improves over time, the yields are usually recovered. On the other hand, it is not uncommon that some farmers continue to struggle with pest problems or are not able to demonstrate the expertise needed for organic farming, in which case conversion back to conventional practices is necessary to prevent further losses. To capture this, we assume there are two types of producers with different learning capabilities and the type of a producer is unknown prior to the use of the sustainable production practice. On the consumer side, sustainable production has higher value but consumers are heterogenous in the additional utility that they receive from the consumption of the sustainable product. That is, the less sensitive consumers are willing to pay a lower premium for the sustainable product, capturing consumers’ heterogeneous preferences over organic produce in reality.

Under this setting, we characterize the equilibrium adoption rate of the sustainable practice and investigate possible government interventions that are used in practice to promote organic farming, including taxes on the traditional practice (taxes on fertilizers, pesticides), subsidies on the sustainable practice (area payments, subsidies on certification) and a hybrid policy that incorporates both. We find that a zero-expenditure policy in which taxes are used to fund subsidies may benefit either the producers or the consumers but not both. In fact, only positive-expenditure subsidy or hybrid policies can improve social welfare, but this improvement is always less than the government spending. Our results indicate that a subsidy policy outperforms the corresponding hybrid policy that uses the same total expenditure or unit subsidy in achieving higher social welfare while the converse is true in achieving a higher adoption rate and under certain conditions, higher benefit to the consumers. Thus, it is important for the policy maker to determine the priority, whether it is to improve the environmental conditions, benefit the producers or the consumers, when choosing which policy to implement.

We also study the case with financially constrained producers that cannot afford the losses caused by the sustainable practice during the transition phase. This is a common problem for small farmers that struggle with high certification costs, especially in developing countries where the certification process is not centralized and imposes a considerable financial burden on producers. The previous results continue to hold if the financially constrained producers constitute a small fraction of the producer population. On the other hand, if the lack of financial resources restricts sustainable production adoption, it is possible for the policy maker to achieve an improvement in social welfare using a zero-expenditure policy that restores the profitability of the sustainable practice during the transition phase, thus enabling the resource-constrained producers to improve
their profits by converting to sustainable production. Lastly, we calibrate our model using data on conventional and organic egg production in Denmark and investigate the set of policies that can achieve the goals of the Danish government regarding organic production. We find that if the government aims to double the adoption rate of organic egg production as part of the goal of doubling the organically cultivated area by 2020, at least 4.17% of the organic production cost should be subsidized in order to generate a positive impact on social welfare. This would benefit producers but reduce consumer surplus due to low organic yields. In order to benefit both parties while achieving the target adoption rate, the government should implement efforts in improving organic yields and consumer awareness of organic products in addition to producer-based monetary incentives in the form of taxes and subsidies.

The rest of the paper is structured as follows. Section 2 presents the related literature. We describe the model formulation in Section 3 and characterize the equilibrium in Section 4. Interventions are investigated in Section 5 and the case with financially constrained producers is studied in Section 6. Section 7 presents the model calibration and concluding remarks are summarized in Section 8.

2. Related Literature

Our paper contributes to the literature that studies the role of government interventions in new technology adoption, including organic and sustainable farming practices in the agriculture sector, solar panel technology in the energy sector and electric vehicles in the automotive sector. The case of organic farming has attracted attention in the agricultural economics literature. De Ponti et al. (2012) study the yield gap between organic and conventional farming using data from 43 countries and find that the organic yields are on average 20% lower than the conventional yields but there is considerable variation in the yield gap across different crops and regions. More related to our work, there are papers that study the impact of government policies on conversion to organic farming in various European countries. Lohr and Salomonsson (2000) analyze whether subsidies are needed in order to promote organic agriculture by contrasting the case in Europe where conversion subsidies are widely used with the U.S. where the transition to organic farming is mostly market-driven. Using data from Sweden, the authors find that larger and less-diversified farms are the ones requiring subsidies for conversion, and access to market outlets and information sources substitutes for the financial support. Thus, it is concluded that the U.S. organic sector can be supported using market access improvement. Pietola and Lansink (2001) empirically investigate the factors that play a role in the choice of conventional vs. organic farming in Finland. It is found that economic incentives such as price policies and direct subsidies are key components in promoting the transition to organic farming. Using a dynamic utility-efficient programming model and data from the Netherlands, Acs
et al. (2009) investigate the conversion decisions of farmers by incorporating their risk attitudes and show that for a risk neutral farmer, it is optimal to convert to organic farming whereas for a risk averse farmer, it is optimal to convert only if taxes on pesticides or subsidies on conversion are applied or the organic market becomes more stable. Our paper differs from this stream of literature in that we model the producers’ choice of using conventional or organic farming and explore the impact of taxes and subsidies not only on the conversion rate and the producers’ profits but also on the consumer surplus and the return on government spending.

Another branch of literature that is relevant to our work studies subsidies and interventions in various settings. Levi et al. (2013) study the allocation of subsidies in order to increase the consumption of a good that has positive externalities on the society. Other papers investigate the role of subsidies in increasing the availability of malaria drugs (Taylor and Xiao 2014, Kazaz et al. 2016), ensuring efficient distribution of surface water among farms with different proximity to water sources (Dawande et al. 2013) as well as the impact of private and public market information provision (Chen and Tang 2015) and agricultural advice and market forecast provision (Chen and Tang 2015) on farmers’ welfare. Additionally, Alizamir et al. (2015) study two types of farm subsidies (Price Loss Coverage and Agriculture Risk Coverage) practiced widely in the U.S. in order to support farmers’ incomes and investigate their impact on farmers, consumers, and the government. Furthermore, our paper complements the operations management literature that studies consumer subsidies as a means of promoting new technology such as solar panels and electric vehicles. Lobel and Perakis (2011) study the solar panel sector and develop a framework to calculate the optimal subsidy scheme that is to be provided to consumers in order to achieve a target adoption rate while minimizing costs. Motivated by the electric vehicle market, Cohen et al. (2015) study a setting with multiple suppliers in which subsidies are provided to consumers in order to encourage the adoption of the green product, and investigate the impact of competition among suppliers on consumers, suppliers and the government. It is found that when externalities are small, competition hurts the suppliers, benefits the government, but does not always benefit all the consumers whereas in the case of large externalities, consumers always benefit from competition among suppliers. Chemama et al. (2014) explore the impact of fixed and flexible consumer subsidies on the supplier, the consumers and the government expenditure. The authors find that even though a flexible subsidy policy results in higher government expenditure, the uncertainty in the adoption level is lower and the supplier is better-off. Cohen et al. (2016) investigate the role of demand uncertainty in designing consumer subsidies for green technology adoption and show that an increase in demand uncertainty in the case of convex demand functions results in a decrease in the supplier’s profit. The authors show that if the uncertainty in demand is ignored
hog and designing policies, the policy maker can significantly miss the target adoption level. Complementing this stream of literature, we study the role of producer-based interventions in promoting sustainable practices while incorporating competition among producers and a dynamic setting with yield benefits gained from experience.

The papers that are more closely related to our work study producer-based policy interventions with the goal of promoting green technology. Acemoglu et al. (2012) use a dynamic growth model that incorporates environmental constraints to study the role of carbon taxes and research subsidies in technological innovation. It is found that sustainable growth can be achieved with temporary interventions if clean and dirty inputs are sufficiently substitutable and the optimal policy consists of both carbon taxes and research subsidies while avoiding excessive use of taxes. Alizamir et al. (2016) study the policy maker’s problem of determining the prices of the feed-in-tariff policies that are used to promote renewable energy technologies utilizing a dynamic model with learning-by-doing benefits on the cost of the technology. Even though the current practice attempts to preserve the same level of profitability across years, the authors argue that this is rarely optimal and depending on the diffusion and learning rates of the technology, policies with decreasing profitability index might be needed in order to prevent investors from postponing their investment in the renewable technology to a later period. Wang et al. (2016) use a framework in which the benefits from the green technology is uncertain and the government agency takes the capability of the industry to meet regulatory standards into account when introducing a new regulation on a pollutant. The authors show that when the first-mover advantage is low, regulation that considers the industry capability index motivates green technology adoption more effectively compared with a regulation that ignores the capability index. All in all, government regulation in encouraging the adoption of sustainable practices and green technology has drawn attention in the literature. We complement the existing literature on producer-based interventions by incorporating the consumers’ and the government’s perspectives in addition to that of the producers’. That is, we use a model including all the stakeholders in the supply chain and analyze the impact of tax and subsidy policies on the consumer surplus, the government expenditure, and the return on government spending besides the producers’ profits.

3. Model

We consider a two-period model in which producers have two options in terms of the practices that can be implemented in each period with both production practices’ being subject to random yield. The first option is the traditional practice (e.g. conventional farming), denoted by $T$, which is considered to be low cost and may potentially have higher yield than the sustainable alternative. The alternative option is the high-cost, low-yield sustainable practice (e.g. organic farming), denoted
by $S$, which is valued higher by the consumers. Period 1 is the transition phase during which the conversion from conventional to organic farming occurs given that the producer chooses to convert and period 2 is considered to be the long-run steady state. Producer (she) and consumer (he) sides of the model are described in depth in the following sections.

3.1. Producers

We assume each producer is infinitesimally small and the total producer population has unit mass. This framework is well suited for settings in which each farmer is small compared to the total population and acts as a price taker. Each producer has unit capacity and uses either the traditional or the sustainable practice in period 1 and period 2. Our model incorporates learning in the sustainable practice in terms of an increase in the yield. In fact, as Rundgren (2006) states, yields of organic farming improve over time as soil fertility is recovered and farmers learn new techniques. In practice, a farmer’s success in adopting organic farming depends on a number of factors including the extent to which synthetic fertilizers and pesticides were used before conversion to organic practices, the farmer’s expertise in avoiding pest attacks and weeds without the use of chemicals, and the soil conditions and fertility. The extent to which a farmer will be successful in implementing sustainable practices is revealed once the farmer experiments with these practices during the transition phase. In the case of conventional vs. organic production, while some farmers can easily convert to organic farming, some fail to recover the yields even after the transition phase due to the aforementioned factors. To capture this, we assume that there are two types of producers, fast learners and slow learners, and our setting is such that depending on the producer’s type, an improvement in the yield of the sustainable practice is realized in period 2 conditional on its being utilized by the producer in period 1. Producers do not know their types in period 1, that is, prior to having any experience with the sustainable practice. If a producer adopts the sustainable practice in period 1, she learns her type at the end of the period and uses that information when choosing which practice to adopt in period 2. On the other hand, producers that do not convert to the sustainable practice in period 1 do not learn their types. The fraction of fast learners in the producer population is assumed to be a random variable. Since the traditional practice is well established, producers using the traditional practice do not experience an improvement in yield due to learning. The notation is summarized in Table 1.

Even though organic farming causes a decline in input costs as the use of synthetic inputs is prohibited, it is more labor intensive than conventional farming, resulting in higher overall unit cost (Bruinsma 2003, Wynen 2003, Kupfer 2007). To capture that, we assume $c_S > c_T$. In our model, $\sigma_S$ and $\rho_{ST}$ do not change as a result of learning as it is assumed that the variability in yield is mainly caused by the uncertain weather conditions, hence not affected by the producers’
Table 1 Notation

<table>
<thead>
<tr>
<th>Notation</th>
<th>Explanation</th>
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<tbody>
<tr>
<td>$\theta_i$</td>
<td>Type of a producer, $\theta_i \in {\theta_f, \theta_s} \text{ where } \theta_f &gt; \theta_s$</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Fraction of fast learners in the producer population with mean $\bar{\alpha}$ and standard deviation $\sigma_\alpha$</td>
</tr>
<tr>
<td>$\phi_T$</td>
<td>Yield of the traditional practice with mean $\mu_T$ and standard deviation $\sigma_T$</td>
</tr>
<tr>
<td>$\phi_S$</td>
<td>Yield of the sustainable practice in period 1 with mean $\mu_S$ and standard deviation $\sigma_S$</td>
</tr>
<tr>
<td>$\phi_i^S$</td>
<td>Yield of the sustainable practice for producer type $i$ in period 2 with mean $\mu_i^S$ and standard deviation $\sigma_S$</td>
</tr>
<tr>
<td>$\sigma_{TS}$</td>
<td>Covariance between the yields of the traditional and sustainable practices</td>
</tr>
<tr>
<td>$c_j$</td>
<td>Unit production cost of practice $j$, $j \in {T, S}$ where $c_s &gt; c_T$</td>
</tr>
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</table>

experience in using the sustainable practice \(^1\). The improvement in yield due to the experience in using the sustainable practice is modeled as a shift in the yield distribution. That is, provided that a producer of type $\theta_i$ adopts the sustainable practice in period 1, the yield in period 2 is given by $\phi_i^S = \phi_S + \theta_i$. As a result, the expected yield in period 2 is given by $\mu_i^S = \mu_S + \theta_i$. For simplicity, we normalize $\theta_s = 0$.

3.2. Consumers

We consider a continuum of consumers with a total market size $M$. Consumers value the sustainable product higher than its counterpart produced via the traditional practice. We denote the valuation for the end product produced via practice $j$ as $v_j$, $j \in \{T, S\}$, with $v_S > v_T$. Consumers are heterogenous in their utility received from the sustainable good consumption meaning that even though the sustainable good has a higher value than the traditional good, the extent to which that valuation difference plays a role in the consumer’s utility function is dependent on his type. We assume that consumers are uniformly distributed over $[0,1]$ depending on their types. The utility of a consumer of type $s$ from the consumption of a good produced via practice $j$ in period $t$ is given by $u + sv_j - p_jt$ where $u$ is the common utility gained from the consumption of the final product and $p_jt$ is the price of the product in period $t$.

3.3. Market clearing price

Since each producer is small and acts as a price taker, the market price is determined by the total supply and demand such that the market clears in each period. For the following calculations, we suppress the subscript for time for ease of notation, but the derivation presented below holds for both periods 1 and 2.

In order to calculate the prices, we first find the demand given any price pair $(p_T, p_S)$. In equilibrium, there is a consumer of type $\bar{s}$ that is indifferent between the outside option, which is

\(^1\)It is straightforward to extend the results to the case where $\sigma_S$ and $\sigma_{TS}$ change as a result of the improvement in the yield of the sustainable practice.
assumed to yield 0 utility, and purchasing the good produced via the traditional practice, i.e. $u + \bar{s}v_T - p_T = 0$, resulting in $\bar{s} = \frac{p_T - u}{v_T}$. There is another consumer of type $\bar{s} \geq \bar{s}$ that is indifferent between purchasing the good produced via the traditional practice and the one produced via the sustainable practice, i.e. $u + \bar{s}v_T - p_T = u + \bar{s}v_S - p_S$, which results in $\bar{s} = \frac{p_S - p_T}{v_S - v_T}$. Using $\bar{s}$ and $\bar{s}$, one can calculate the demand for the conventional and sustainable products. Let us denote the total demand and supply for the product that is produced via practice $j$ as $Q_j^{Demand}$ and $Q_j^{Supply}$, respectively, for $j \in \{T, S\}$. $Q_T^{Demand}$ and $Q_S^{Demand}$ are given by

$$Q_T^{Demand} = M(\bar{s} - \bar{s}) = M\left(\frac{(p_S - u)v_T - (p_T - u)v_S}{v_T(v_S - v_T)}\right),$$

$$Q_S^{Demand} = M(1 - \bar{s}) = M\left(\frac{v_S - p_S - v_T + p_T}{v_S - v_T}\right).$$

Consequently, the market clearing condition, $Q_j^{Demand} = Q_j^{Supply}$ for $j \in \{T, S\}$, enables us to get the following price functions.

$$p_T = u + v_T \left(1 - \frac{Q_T^{Supply}}{M} - \frac{Q_S^{Supply}}{M}\right)^+,\n$$

$$p_S = u + v_S \left(1 - \frac{v_T Q_T^{Supply}}{v_S M} - \frac{Q_S^{Supply}}{M}\right)^+.$$

Note that $p_S \geq p_T$ due to the higher valuation for the sustainable product. Consumers’ paying a premium for the sustainable product creates incentives for the producers to adopt sustainable practices despite the higher cost. From now on, we normalize $u = 0$ for simplicity. Moreover, we assume that $\phi_T + \phi_S < M$ a.s. so that prices do not fall to zero.

4. Equilibrium Characterization

In this section, we characterize the equilibrium adoption rate of the sustainable practice. First, we assume that $v_S\mu_S < c_S$, i.e. it is not profitable to adopt the sustainable practice in a single-period setting due to the high cost and/or low expected yield. Thus, producers who choose not to convert to the sustainable practice in period 1 again continues with the traditional practice in period 2. This assumption reflects the fact that farmers endure profit losses during the transition phase when they first convert to organic farming with the prospect of higher yields in the future periods. As a result, in the long run, it is expected that the higher costs are compensated by the price premiums and the improvement in yield. In this model, period 1 represents the duration of the initial adoption phase where a producer adopting the sustainable practice experiences low yields. In reality, this could be more than one season, and usually organic farmers have to produce organically for a few years before they can get certification and have access to the organic market. Lower yields in period 1 can be representative of the barriers encountered in reality when transitioning to organic
agriculture. On the other hand, in the second period, the producer starts realizing higher yields, which potentially lasts for a longer period of time than the first period. In order to account for the different durations of the two phases, one has to discount the profits/welfare gained in period 1 and period 2 accordingly. We assign weights to periods 1 and 2 and normalize the weight in the first period to one. Let $w$ denote the weight of the second period where $w > 1$ in order to capture the fact that the post-adoption phase lasts longer than the transition phase. Moreover, we use the following notation in the characterization of the equilibrium.

- $\beta_t$: Fraction of the producer population that adopts the sustainable practice in period $t$,
- $\pi_{j1}$: Expected profit of a producer who adopts practice $j$ in period 1, $j \in \{T, S\}$,
- $\pi_{T2} | \alpha$: Expected profit of a producer who adopts the traditional practice in period 2 given $\alpha$,
- $\pi_{S2} | \alpha$: Expected profit of a type $\theta_i$ producer who adopts the sustainable practice in period 2 given $\alpha$.

Let $\kappa_j = \frac{\mu_j^2 + \sigma_j^2}{M}$ for $j \in \{T, S\}$ and $\kappa_{TS} = \frac{\sigma_{TS} + \mu_T \mu_S}{M}$. $\kappa_T$ and $\kappa_{TS}$ are used with the superscript $i$ and $\mu_S$ is replaced with $\mu_S + \theta_i$ whenever the type of the producer is known. Lastly, let us define $\kappa_\alpha = \alpha^2 + \sigma_\alpha^2$. We can now calculate $\pi_{j1}$ for $j \in \{T, S\}$.

\[ \pi_{T1} = \mathbb{E} \left[ p_{T1} \phi_T \right] - c_T = \mathbb{E} \left[ v_T \left( 1 - \frac{\phi_T (1 - \beta_1)}{M} \right) \phi_T - c_T = v_T \mu_T - c_T - v_T \kappa_T (1 - \beta_1) - v_T \kappa_{TS} \beta_1. \] (1)

Similarly,

\[ \pi_{S1} = v_S \mu_S - c_S - v_T \kappa_{TS} (1 - \beta_1) - v_S \kappa_S \beta_1. \] (2)

We assume that $v_T \mu_T - c_T - v_T \kappa_T \geq 0$, i.e. the expected profit obtained by using the traditional practice is non-negative even if every other producer is also using the traditional practice. This assumption is based on the fact that for many years conventional farming has constituted the majority of farming practices while sustaining profitability. It is also assumed that $v_T \mu_T - c_T - v_T \kappa_{TS} \geq 0$, meaning that the expected profit obtained from using the traditional practice is non-negative even if every other producer is using the sustainable practice with the improved yield. That is, the market size is large enough such that it is always possible to generate positive profits through the traditional practice. Before deriving $\pi_{T2} | \alpha$ and $\pi_{S2} | \alpha$ for $\theta_i \in \{\theta_f, \theta_s\}$, we establish the characteristics of the equilibrium with the following proposition.

**Proposition 1.** There exists a unique equilibrium where out of the producers that adopt the sustainable practice in period 1, only the fast learners continue with the sustainable practice in period 2. Slow learners convert back to the traditional practice.
Producers that are not able to improve their yields convert back to the traditional practice to prevent further losses. In the case of organic farming, it is not uncommon for farmers to revert to conventional farming once they struggle with pest attacks and weeds, and hence cannot absorb the high costs of organic practices. Using Proposition 1, we can now calculate $\pi_{T2|\alpha}$ and $\pi_{S2|\alpha}^s$ for $\theta_i \in \{\theta_f, \theta_s\}$ as follows.

$$\pi_{T2|\alpha} = \mathbb{E} \left[ v_T \left( 1 - \frac{\phi_T (1 - \beta_2)}{M} - \frac{\phi_S^f \beta_2}{M} \right) \phi_T \right] - c_T$$

$$= v_T \mu_T - c_T - v_T \kappa_T (1 - \alpha \beta_1) - v_T \kappa_T^f \alpha \beta_1$$  \hspace{1cm} (3)

where the second equality follows from $\beta_2 = \alpha \beta_1$ as in equilibrium only fast learners continue using the sustainable practice in period 2. Similarly,

$$\pi_{S2|\alpha}^f = v_S (\mu_S + \theta_f) - c_S - v_T \kappa_T^f (1 - \alpha \beta_1) - v_S \kappa_S^f \alpha \beta_1,$$ \hspace{1cm} (4)

$$\pi_{S2|\alpha}^s = v_S (\mu_S + \theta_s) - c_S - v_T \kappa_T^s (1 - \alpha \beta_1) - v_S \kappa_S^s + \frac{\mu_S (\theta_f + \theta_s) + \theta_f \theta_s}{M} \alpha \beta_1$$

$$= v_S \mu_S - c_S - v_T \kappa_T (1 - \alpha \beta_1) - v_S \left( \kappa_S + \frac{\mu_S \theta_f}{M} \right) \alpha \beta_1$$  \hspace{1cm} (5)

where the last equality holds since $\theta_s = 0$. Note that $\pi_{S2|\alpha}^s < 0 \ \forall \alpha \in [0,1]$. In equilibrium, in order to avoid a profitable deviation to the outside option of not producing, it should be the case that

$$\pi_{T1} \geq 0 \ \text{and} \ \mathbb{E}_\alpha [\pi_{T2|\alpha}] \geq 0.$$  \hspace{1cm} (6)

Note that the second period condition contains an expectation over $\alpha$. Since each producer that adopts the sustainable practice in period 1 only observes her own type at the end of that period, not the realization of $\alpha$, expected profit of a producer in period 2 entails an expectation to be taken over $\alpha$. These conditions are satisfied since $v_T \mu_T - c_T - v_T \kappa_T \geq 0$ and $v_T \mu_T - c_T - v_T \kappa_T^f \geq 0$. Moreover, since only the fast type producers continue using the sustainable practice in period 2, the following condition has to hold in the second period.

$$\mathbb{E}_\alpha [\pi_{S2|\alpha}^f] \geq \mathbb{E}_\alpha [\pi_{T2|\alpha}] \geq \mathbb{E}_\alpha [\pi_{S2|\alpha}^s].$$  \hspace{1cm} (7)

The second inequality holds since $\mathbb{E}_\alpha [\pi_{T2|\alpha}] \geq 0$ and $\mathbb{E}_\alpha [\pi_{S2|\alpha}^s] < 0$ whereas the first inequality is satisfied when

$$\bar{\alpha} \beta_1 (v_S \kappa_S^f - 2v_T \kappa_T^f + v_T \kappa_T) \leq v_S \mu_S - c_S - v_T \mu_T + c_T + v_T \kappa_T - v_T \kappa_T^f$$  \hspace{1cm} (8)

holds. We will verify that this condition is satisfied once $\beta_1$ is derived.

In period 1, the equilibrium is given by the indifference condition such that a producer who practices traditional production techniques in periods 1 and 2 has the same expected profit as the
producer who adopts the sustainable practice in period 1 and decides whether to continue using it depending on the realization of her type. This indifference condition is presented below.

$$\pi_{T1} + wE_\alpha[\pi_{T2}] = \pi_{S1} + wE_\alpha[\alpha \pi'_{S2} \alpha + (1 - \alpha) \pi_{T2}] .$$ (9)

To ensure an interior solution, we assume that there exists a profitable deviation to sustainable production if all of the producers use the traditional practice, which is given by the following condition.

$$v_S\mu_S - v_T\kappa_{TS} - c_S + w\bar{\alpha} (v_S\mu'_S - v_T\kappa'_{TS} - c_S) > (v_T\mu_T - v_T\kappa_T - c_T) (1 + w\bar{\alpha}) .$$ (10)

Similarly, it is assumed that if all of the producers produce via the sustainable option, there exists a profitable deviation to the traditional practice, as given below.

$$v_S\mu_S - v_S\kappa_S - c_S + wE_\alpha[\alpha (v_S\mu'_S - v_T\kappa'_{TS} (1 - \alpha) - v_S\kappa_S \alpha - c_S)]
< v_T\mu_T - v_T\kappa_{TS} - c_T + wE_\alpha[\alpha (v_T\mu_T - v_T\kappa_T (1 - \alpha) - v_T\kappa'_{TS} \alpha - c_T)] .$$ (11)

Using (1), (2), (3), (4) and (9), we can calculate $\beta_1$, the adoption rate of the sustainable practice in equilibrium. First, let us define the following for ease of notation.

$$X_0 = v_S\kappa_S - 2v_T\kappa_{TS} + v_T\kappa_T,$$

$$X_1 = v_S\kappa'_S - 2v_T\kappa'_{TS} + v_T\kappa_T,$$

$$Y_0 = v_S\mu_S - c_S - v_T\mu_T + c_T + v_T\kappa_T - v_T\kappa_{TS},$$

$$Y_1 = v_S\mu'_S - c_S - v_T\mu_T + c_T + v_T\kappa_T - v_T\kappa'_{TS},$$

$$X = X_0 + w\kappa_X X_1,$$

$$Y = Y_0 + w\bar{\alpha} Y_1.$$ 

**Proposition 2.** The equilibrium solution to (9) is given by $\beta_1 = X / Y$ and satisfies condition (8).

The expected fraction of the producer population that continue using the sustainable practice in the second period is then given by $\bar{\alpha} \beta_1$.

**Corollary 1.** Adoption of the sustainable practice in the first period increases in $w$, $c_T$ and decreases in $c_S$, $\sigma_\alpha$. Moreover, it increases in $\bar{\alpha}$ if $\bar{\alpha} < \hat{\alpha}$, decreases otherwise, where $\hat{\alpha} = \sqrt{X_0^2 Y_0^2 + w X_0 Y_0 (X_0 + w \sigma^2 \alpha X_1) - X_1 Y_0} / w X_1 Y_1$. On the other hand, expected adoption in period 2 increases in $\bar{\alpha}$.

Sustainable practices with longer lifespan are more desirable from the producers’ perspective. For instance, once a producer is proficient in using organic production techniques, she expects to produce organically for a long period of time, providing an incentive for the producer to adopt organic farming. Conversely, in the case of hybrid rice commercialization program implemented in the Philippines, farmers need to buy the hybrid seeds every year, resulting in a practice with
very short lifespan, which causes resistance on the producer side to adopt the practice. Moreover, adoption of the sustainable practice is higher as the traditional practice gets costlier or the cost of the sustainable practice decreases. When the fraction of fast learners, i.e. the success rate of sustainable practice adoption, is higher than a threshold, the benefit gained from converting to the sustainable practice decreases as the premiums are expected to shrink. As a result, in cases where farmers’ transition is expected to be easy (it is usually easier for small farmers to switch to organic farming as they are already familiar with the underlying practices), the adoption rate in the initial phase is not very high due to the amount of competition expected to occur in the sustainable market in the long run. Nevertheless, the long-run fraction of producers that adopt the sustainable practice increases as the success rate increases. Lastly, uncertainty in the success rate has an adverse effect on sustainable practice adoption due to the increased risk of profit losses.

Next, we calculate the producers’ expected profits, the consumer surplus and the social welfare, denoted by \( \Pi_P \), \( \Pi_C \) and \( \Pi_{SW} \), respectively, where \( \Pi_{SW} = \Pi_P + \Pi_C \). Due to condition (9), all producers incur the same total expected profit. Thus, we have \( \Pi_P = \pi T_1 + wE_\alpha [\pi T_2|\alpha] \). Consumer surplus is calculated as shown below.

\[
\Pi_C = E_{\phi T, \phi S, \alpha} \left[ \sum_{t=1}^{2} M \left( \int_{\tilde{s}_t}^{\tilde{s}_t}(sv_T - p_{Tt})\,ds + \int_{\tilde{s}_t}^{1}(sv_S - p_{St})\,ds \right) w1\{t = 2\} \right]
= \frac{1}{2} \left( v_T \kappa_T (1 - \beta_1)^2 + 2v_T \kappa_{TS} \beta_1 (1 - \beta_1) + v_S \kappa_S \beta_1^2 + wE_\alpha \left[ v_T \kappa_T \left( 1 - \alpha \beta_1 \right)^2 + 2v_T \kappa_{TS} \alpha \beta_1 \left( 1 - \alpha \beta_1 \right) + v_S \kappa_S \alpha^2 \beta_1^2 \right] \right)
= \frac{1}{2} \left( v_T \kappa_T (1 - \beta_1)^2 + 2v_T \kappa_{TS} \beta_1 (1 - \beta_1) + v_S \kappa_S \beta_1^2 + w \left( v_T \kappa_T + 2\bar{\alpha} \beta_1 v_T \left( \kappa_{TS} - \kappa_T \right) + \kappa_\alpha \beta_1^2 \left( v_S \kappa_S - 2v_T \kappa_{TS} + v_T \kappa_T \right) \right) \right).
\]

5. Interventions
In this section, we investigate the effectiveness of a tax policy on the traditional practice, a subsidy policy on the sustainable practice and a hybrid policy that incorporates both in terms of their impact on sustainable practice adoption, surplus allocation between producers and consumers and return on government spending. Tax policy is often implemented as a tax on fertilizers, pesticides, etc. in order to diminish the use of these synthetic inputs. Subsidy policy is predominantly in the form of area payments though some countries provide subsidies on the certification costs as well. We assume that interventions are implemented during the transition phase (period 1) to promote sustainable practice adoption and withdrawn in the long run (period 2).

Let \( \Delta c_T \) and \( \Delta c_S \) denote the unit tax applied to the traditional practice and the unit subsidy applied to the sustainable practice, respectively. Note that if \( \Delta c_S > 0 \) and \( \Delta c_T = 0 \), the intervention
serves as a subsidy-only policy whereas the case with $\Delta c_T > 0$ and $\Delta c_S = 0$ corresponds to a tax-only policy. We refer to the case with $\Delta c_S > 0$ and $\Delta c_T > 0$ as a hybrid policy. The adoption rate of the sustainable practice in period 1 under a $(\Delta c_S, \Delta c_T)$-policy is given by

$$\beta_1^{(\Delta c_S, \Delta c_T)} = \frac{Y + \Delta c_S + \Delta c_T}{X} = \beta_1 + \frac{\Delta c_S + \Delta c_T}{X}.$$ 

It is straightforward to show that the equilibrium conditions continue to hold in this case. We assume that $\Delta c_S + \Delta c_T < X - Y$ so that $\beta_1^{(\Delta c_S, \Delta c_T)} < 1$. Let $\Delta \Pi_P$, $\Delta \Pi_C$ and $\Delta \Pi_{SW}$ denote the change in producers’ expected profits, consumer surplus and social welfare, respectively, under a $(\Delta c_S, \Delta c_T)$-policy compared to the benchmark case with no intervention. Let us define $Z = v_T (\kappa_T - \kappa_{TS} + \bar{w}(\kappa_T - \kappa_{TS}^f))$. Then, $\Delta \Pi_P$, $\Delta \Pi_C$ and $\Delta \Pi_{SW}$ are given by

$$\Delta \Pi_P = (\Delta c_S + \Delta c_T) \frac{Z}{X} - \Delta c_T,$n(12)$$

$$\Delta \Pi_C = \frac{1}{2} (\Delta c_S + \Delta c_T) \left( \beta_1 + \beta_1^{(\Delta c_S, \Delta c_T)} - \frac{2Z}{X} \right),$$

$$\Delta \Pi_{SW} = \frac{1}{2} (\Delta c_S + \Delta c_T) \left( \beta_1 + \beta_1^{(\Delta c_S, \Delta c_T)} \right) - \Delta c_T.$n(14)$$

Moreover, let us denote the government expenditure as

$$\zeta^{(\Delta c_S, \Delta c_T)} = \Delta c_S \beta_1^{(\Delta c_S, \Delta c_T)} - \Delta c_T \left( 1 - \beta_1^{(\Delta c_S, \Delta c_T)} \right).$$

5.1. Zero-Expenditure Hybrid Policy

Zero-expenditure policies, entailing the use of the income from the tax on the traditional practice to subsidize the sustainable practice, might be desirable from the government’s perspective as the resulting intervention is self-funded. However, in the following proposition, we show that such policies fail to improve social welfare. First, using (14) and (15), let us rewrite $\Delta \Pi_{SW}$ as

$$\Delta \Pi_{SW} = \frac{1}{2} \left( \zeta^{(\Delta c_S, \Delta c_T)} + \Delta c_S \beta_1 - \Delta c_T (1 - \beta_1) \right).$$

**Proposition 3.** Any zero-expenditure hybrid policy results in a reduction in social welfare.

The reason social welfare declines under a zero-expenditure policy is that under this setting, the equilibrium with no intervention in fact achieves the social optimum as each producer is small and acts as a price taker and the prices are determined endogenously by market clearing. As a result, interventions that do not involve a positive payment from the government cannot increase social welfare. Figure 1a illustrates this point. Point $A$ is the equilibrium adoption rate of the sustainable practice under the no-intervention benchmark. The maximum social welfare in the case of a centralized agricultural supply chain under no intervention or a hybrid policy with zero expenditure
is also achieved at Point A. This observation depicts that the equilibrium solution in the case of competitive producers achieves supply chain coordination. On the other hand, the competitive equilibrium under a hybrid policy with zero government expenditure is given at point B, and generates a lower social welfare compared to the competitive equilibrium under no intervention. However, even though social welfare declines due to a zero-expenditure policy, either producers or consumers may benefit from the intervention as shown in Figure 1b. This is indeed an important consideration as policy makers may not always place equal emphasis on the improvement in producers’ incomes and consumers’ access to healthy and affordable food. In the case of products that are widely used by all consumer groups, especially children, such as dairy products, the government’s priority might be to support consumers’ well-being. For instance, milk is one of the products with highest organic consumption in Denmark and according to Danish Agriculture & Food Council, half of the milk consumed by pupils in Danish schools is organic. On the other hand, when the crop in consideration is mainly produced for exports but not for local consumption, then the policy maker may prioritize supporting producers’ incomes higher. The next proposition draws attention to such distinction.

Figure 1  Social welfare functions under central optimization and perfect competition

![Figure 1](image)

Note. \( v_T = 0.6, \mu_T = 1.5, \sigma_T = 0.4, c_T = 0.6, v_S = 1, \mu_S = 1.25, \sigma_S = 0.5, c_S = 1.35, \sigma_{TS} = 0.1, \theta_I = 0.55, \alpha = 0.7, \sigma_\alpha = 0.1, w = 6, M = 10, \Delta c_T = 0.05, \Delta c_S = 0.25.\)

**Proposition 4.** Under a zero-expenditure hybrid policy,

(i) If \( w_\alpha (v_S \mu_T^C - c_S - v_T \mu_T + c_T) > v_T \mu_T - c_T - v_S \mu_S + c_S, \) consumer surplus increases whereas expected profits of producers decrease,

(ii) If \( w_\alpha (v_S \mu_T^C - c_S - v_T \mu_T + c_T) < v_T \mu_T - c_T - v_S \mu_S + c_S, \)
(a) If \( \Delta c_S + \Delta c_T < v_T \mu_T - c_T - v_S \mu_S + c_S - w \bar{\alpha} (v_S \mu_S^f - c_S - v_T \mu_T + c_T) \), consumer surplus decreases whereas expected profits of producers increase,

(b) If \( \Delta c_S + \Delta c_T > 2 (v_T \mu_T - c_T - v_S \mu_S + c_S - w \bar{\alpha} (v_S \mu_S^f - c_S - v_T \mu_T + c_T)) \), consumer surplus increases whereas expected profits of producers decrease,

(c) Otherwise, both the consumer surplus and the expected profits of producers decrease.

If the gap between the maximum margins of the two practices is not very big, i.e. the sustainable practice is not financially detrimental compared to the traditional practice or the expected improvement in the yield of the sustainable practice is high enough so that adopters are able to recover their losses in the long run, the sustainable practice is desirable from the producers’ perspective even in the absence of any intervention. In this case, a zero-expenditure government intervention pushes adoption to a higher level, increasing competition in the sustainable market for adopters as well as introducing taxes for non-adopters, thus hurting the overall producer population. It is considered that small farmers can adjust to organic practices more easily since the conventional methods they use resemble to those of organic farming due to the lack of financial resources to purchase vast amounts of chemical inputs. As a result, the initial profitability gap between the two practices might be lower for smallholders. For regions where small farmers constitute the majority, the policy maker may be likely to hurt the producers and the social welfare through the implementation of a zero-expenditure policy. Nevertheless, consumers benefit from the increased availability of sustainable products.

On the other hand, if the expected future profit gains from the sustainable practice do not cover the losses during the conversion period, it is possible to benefit the producers through a zero-expenditure policy. Since the intervention brings the two alternative production options closer in terms of profitability (by reducing the cost of the sustainable option and increasing the cost of the traditional option), the sustainable practice becomes a viable option for producers. In this case, the total amount of tax and subsidy determines whether the producers gain or not. If the pressure on the producers is high such that an adoption rate that is not justified by the long-run benefits is attained as a result of the intervention, producers incur losses. Meanwhile, consumers are likely to suffer from the adverse characteristics of the sustainable practice, such as low yields, as those are not addressed by the intervention. However, it is possible to benefit the consumers using a policy that exerts high pressure on the producers to convert to the sustainable practice, making up for the yield losses by substantially increasing adoption, and thus the availability of sustainable products. On the other hand, if the intervention is such that the pressure on the producers induces an adoption rate that is higher than the level beneficial to them while the rate needed to benefit the consumers is not reached, then both the producers and the consumers incur losses.
Lastly, as illustrated by point C in Figure 1a, an increase in social welfare can be attained in the competitive equilibrium through a policy that entails positive government spending. We will explore such policies in the next section.

5.2. Tax, Subsidy and Non-Zero-Expenditure Hybrid Policies

We now turn to a broader class of policies with non-zero expenditure that can in fact achieve an improvement in social welfare through the promotion of sustainable practices. The next proposition provides a characterization of such policies.

**Proposition 5.** Social welfare increases under any subsidy-only policy and decreases under any tax-only policy. It increases under a hybrid policy if and only if

\[(\Delta c_S + \Delta c_T)^2 + 2Y \Delta c_S - 2(X - Y) \Delta c_T > 0.\]

Since subsidy policies incentivize producers to adopt sustainable production through a reduction in costs, social welfare always improves. Conversely, tax policies encourage sustainable practice adoption by making the alternative costlier, resulting in a decline in social welfare. Depending on the unit subsidy and unit tax contained in a hybrid policy, it is possible to achieve an improvement in welfare. Even though the overall welfare increases, the allocation between the producers and the consumers needs to be investigated to understand the impact of these policies on both parties, which brings us to the following proposition.

**Proposition 6.** If

\[v_S \mu_S - c_S - v_T \mu_T + c_T + w \alpha (v_S \mu_S^f - c_S - v_T \mu_T + c_T) > v_T (\kappa_T - \kappa_{TS} + w \alpha (\kappa_T - \kappa_{TS}^f)),\]

the change in producers’ expected profits is less than the change in consumer surplus under any policy. Otherwise, the change in producers’ expected profits is greater than that of consumer surplus if and only if

(i) \(\Delta c_S < 2(2Z - Y)\) for a subsidy-only policy,

(ii) \(\Delta c_T < 2(2Z - X - Y)\) for a tax-only policy,

(iii) \((\Delta c_S + \Delta c_T)^2 - 2(\Delta c_S + \Delta c_T)(2Z - Y) + 2X \Delta c_T < 0\) for a hybrid policy.

**Corollary 2.** If

\[v_S \mu_S - c_S - v_T \mu_T + c_T + w \alpha (v_S \mu_S^f - c_S - v_T \mu_T + c_T) < v_T (\kappa_T - \kappa_{TS} + w \alpha (\kappa_T - \kappa_{TS}^f)),\]

the set of hybrid policies that generate a greater impact on producers compared to consumers expands as \(c_S\) increases or \(v_S, \sigma_S, c_T, \sigma_\alpha\) decrease.

The left hand side of the condition presented in Proposition 6 is merely the difference in the expected total maximum margins of the sustainable and traditional practices over periods 1 and 2. If the difference is high enough, i.e. the sustainable practice is economically advantageous, then the producers are incentivized to adopt the sustainable practice even in the absence of any government intervention. Hence, when the policy maker intervenes to increase adoption further,
increasing competition reduces profit margins of sustainable production, thus limiting the benefit to producers. On the other hand, as the sustainable practice becomes more disadvantageous in terms of profitability, the intervention from the government attains a higher impact on producers as long as the taxes are not too high. Producers extract higher benefit from the intervention compared to consumers under high-subsidy, low-tax policies whereas low-subsidy, high-tax policies result in a higher benefit to consumers as depicted in Figure 2a.

As sustainable production becomes less profitable or traditional production becomes less costly, the profitability gap between the two alternatives increases, resulting in a greater need from the producers’ perspective for a government intervention that makes the two options economically comparable, and hence, expanding the set of policies that generate a higher impact on producers. Same result holds as the variability in the sustainable production yield decreases since the likelihood of high yield realizations decreases, undermining the potential gains from sustainable production. Moreover, as the uncertainty in the success rate decreases, producers are encouraged to adopt the sustainable practice, and a government intervention can accentuate the incentives further, thus benefiting producers more.

Figure 2  Impact on producers’ profits, consumer surplus and government surplus under a \((\Delta c_S, \Delta c_T)\)-policy

![Figure 2](image)

Note. \(v_T = 0.6, \mu_T = 1.5, \sigma_T = 0.45, c_T = 0.75, v_S = 1, \mu_S = 1.1, \sigma_S = 0.5, c_S = 1.2, \sigma_{TS} = 0.01, \theta_f = 0.3, \bar{a} = 0.5, \sigma_a = 0.1, w = 6, M = 10.\)

Given that the policy maker can achieve an increase in social welfare via positive-expenditure interventions, it is important to have an understanding of the net benefit/loss that the government
incurs through these policies. In order to do that, we define the net government surplus, denoted by $\Delta \Pi_G$, as follows.

$$\Delta \Pi_G = \Delta \Pi_{SW} - \zeta^{(\Delta c_S, \Delta c_T)}$$

$$= \frac{1}{2} (\Delta c_S \beta_1 - \Delta c_T (1 - \beta_1) - \zeta^{(\Delta c_S, \Delta c_T)})$$

$$= \frac{1}{2} (\Delta c_S + \Delta c_T) \left( \beta_1 - \beta_1^{(\Delta c_S, \Delta c_T)} \right)$$

where the second equality follows from (16).

**Proposition 7.** Government surplus is negative for any policy. It is increasing in $\bar{\alpha}$, $\sigma_\alpha$ and $w$, and decreasing in $\sigma_{TS}$.

As Proposition 7 states, even though an improvement in social welfare can be achieved through various subsidy-only and hybrid policies, the return on government spending is negative under any policy. It is important to note that this result does not consider environmental externalities or health benefits. In fact, the policy maker may place higher weight on improving social welfare than the expenditure amount that can achieve such an improvement. This could be the case if the environmental and/or health benefits from sustainable production play an important role in the welfare of producers and consumers. For instance, it is known that organic farming helps restore biodiversity and soil fertility, which may have yield benefits, and the reduction in the use of chemical inputs has important health benefits (CBTF 2008). Moreover, it could also be that the government has excess budget to be spent on agricultural subsidies, which would then result in higher emphasis in social welfare improvement. To capture such cases, we define $\gamma$-adjusted government surplus, denoted by $\Delta \Pi_G$, as $\Delta \Pi_G = \gamma \Delta \Pi_{SW} - \zeta$ where $\gamma > 1$. As shown in Figure 2b, as $\gamma$ increases, the government surplus is positive for a larger set of policies. Moreover, policies with lower unit tax generate a positive return for the policy maker for a larger set of unit subsidy values compared to the policies with higher unit tax.

As more producers are capable of sustaining the transition, i.e. the expected success rate is higher, or the uncertainty in the success rate decreases, there is less risk in government funds’ being depleted by the subsidies on the producers who fail to maintain sustainable production, thus increasing the government surplus. Furthermore, government surplus is higher for sustainable practices with longer lifespan. Conversely, in the case of traditional and sustainable practices with higher yield covariance, government surplus is lower since high covariance diminishes the risk pooling effect, undermining the benefit from utilizing two production practices.

We now turn to the question of whether there is a dominating $(\Delta c_S, \Delta c_T)$-policy. From Proposition 5, we know that even though a tax-only policy increases sustainable practice adoption, such an
increase is in fact not beneficial for the welfare without the compensation for the costs associated with the transition to the new equilibrium. On the other hand, subsidy-only and hybrid policies can achieve an improvement in social welfare, so it is important to understand how these policies compare in achieving various goals that the policy maker might have. The following propositions address that question.

**Proposition 8.** Using the same unit subsidy \( \Delta c_S \), social welfare achieved by the subsidy-only policy is greater than or equal to the one achieved by the hybrid policy (with any unit tax) and the same holds for the government surplus. However, the hybrid policy costs less if and only if \( 2\Delta c_S + \Delta c_T < X - Y \).

**Proposition 9.** For any given hybrid policy, there exists a subsidy-only policy that incurs the same expenditure while achieving social welfare that is greater than or equal to the one of the hybrid policy. However, the adoption rate under such subsidy-only policy is less than or equal to the adoption rate under the hybrid policy.

Proposition 8 states that if there is a specific unit subsidy to be implemented by the policy maker, which might be the case when the policy maker aims to guarantee a minimum profit margin to sustainable practice adopters, then in terms of social welfare and return on government spending, the subsidy-only policy outperforms the hybrid policy that funds some portion of the expenditure via taxes. However, the converse is true in achieving a higher adoption rate as both the same unit subsidy and the additional tax embedded in the hybrid policy moves the equilibrium adoption to a higher level than the subsidy-only policy. Moreover, the subsidy-only policy may cost less to the government as the higher adoption rate under the hybrid policy requires the government to pay more subsidies while the taxes collected from the non-adopter producers may not make up for the difference in the subsidy payments between the hybrid and the subsidy-only policy. As stated in Proposition 9, keeping the government spending fixed, it is found that the total amount of incentives promoting sustainable practice adoption is higher under the hybrid policy, resulting in a higher adoption rate under the hybrid policy compared to the subsidy-only policy. Nevertheless, the subsidy-only policy achieves higher social welfare.

If the policy maker's goal is to protect the environment through increasing the use of sustainable practices, then increasing adoption would be the priority, making the hybrid policy more desirable. For instance, in Denmark, protection of the aquatic environment and reducing the use of pesticides constitute the main motivation for policy implementations that started the conversion to organic farming (CBTF 2008). On the other hand, if the goal is to achieve higher social welfare, then subsidy-only policies are more effective. However, depending on whether the producers or the consumers are prioritized, hybrid policies may perform better as shown in the following proposition.
Proposition 10. If \( \omega \left( v_S \mu_T - c_S - v_T \mu_T + c_T \right) > v_T \mu_T - c_T - v_S \mu_S + c_S \), there exists a hybrid policy that achieves higher consumer surplus than the subsidy-only policy under the same expenditure. Under the same condition, the converse is true in terms of achieving higher producers’ profits.

As shown before, if the gap between the maximum margins of the two practices is not very big, then the sustainable practice is desirable from the producers’ perspective even in the absence of any intervention. In this case, interventions that generate higher adoption undermines the gain to the producers due to the increased competition in the sustainable market whereas the consumers benefit from the increased availability of sustainable products. Consequently, a hybrid policy is more effective than the subsidy-only policy that incurs the same expenditure in terms of achieving higher consumer welfare while the opposite is true for producers’ profits. For instance, when sustainable production in the staple food of the country is important for consumers’ having access to healthy food options, the policy maker can subject producers to taxes on the non-sustainable practices in order to improve consumers’ welfare.

6. The Case with Financially Constrained Producers

In this section, we will consider the case where some portion of the producers are financially constrained in that they cannot afford the profit losses during the initial transition phase. Since the sustainable practice is costly and the low yields during the conversion period result in losses, even if the losses are expected to be recovered in the later periods, some producers may not have the financial resources to get through the conversion period. This problem is often encountered in the case of small farmers that have to endure high certification costs. In fact, certification costs are an important factor that prevents farmers from converting to organic farming (Rustin 2015). In most countries, these costs amount to thousands of dollars. Small farmers usually have difficulty in paying high certification costs, especially in developing countries where the certification process is not centralized or well established. In China, farmers are charged approximately $500 per day for the site visit, and usually a certification application requires three to ten such visits. In India, the daily rate of an inspection visit amounts to no less than $300 (IFAD 2005). Similar situations exist in Latin American countries as well (IFAD 2003). Such costs constitute a big obstacle in sustainable practice adoption as the producers that cannot undertake these costs have to forego the opportunity to convert to sustainable production. In this section, we will revisit the interventions studied previously to understand the impact of policy choice in the presence of producers that cannot afford conversion without the support from the government.

Let \( \delta \) denote the fraction of producers that are financially constrained. Moreover, let us denote the equilibrium adoption rate of the sustainable practice in period 1 with no intervention and under
a \((\Delta c_S, \Delta c_T)\) policy as \(\tilde{\beta}_1\) and \(\tilde{\beta}_1^{(\Delta c_S, \Delta c_T)}\), respectively. In the absence of subsidies, the expected profit from sustainable production, given by \(\pi_S\) in (2), is negative for any adoption rate, preventing the financially constrained producers from converting to the sustainable practice. The following proposition characterizes the equilibrium adoption rate in this case.

**Proposition 11.** Given the equilibrium adoption rate in the absence of financially constrained producers as \(\beta_1 = \frac{Y}{X}\), in the case with financially constrained producers, if \(\delta \leq 1 - \beta_1\), then \(\tilde{\beta}_1 = \beta_1\). Otherwise, \(\tilde{\beta}_1 = 1 - \delta\).

Presence of financially constrained producers only affects sustainable production adoption if long-run benefits from conversion is high so that adoption would be high if producers could undertake the losses during the transition period. If this is not the case, adoption is adversely affected only if the fraction of resource-constrained producers is high. That is, in cases where the sustainable production is considered to be niche and only a small fraction of producers can adopt it even among the ones that can afford the transition, financially constrained producers do not play a role in impacting the adoption rate. For instance, in some developing countries where the domestic organic market is not well established and the barriers to exports are hard to overcome, organic farming is practiced only by a small fraction of producers and even if the producers can afford the losses during the conversion period, the majority of them might not be willing to convert as long-run profits are not very promising due to these barriers.

On the other hand, when there is substantial domestic market potential as well as export opportunities, if organic production is restricted due to lack of financial flexibility on the producer side, the policy maker may need to intervene in order to not only increase the producers’ flexibility to choose between the alternative practices but also enhance the consumer welfare with an increase in the availability of sustainable products. The policy maker can only achieve conversion to the sustainable practice by the financially constrained producers if the expected profit from sustainable production during the transition phase is non-negative under the policy. Otherwise, the intervention can only increase adoption to the extent of the fraction of producers that can afford the conversion, which is shown by the following proposition.

**Proposition 12.** Under a \((\Delta c_S, \Delta c_T)\) policy,

(i) If \(\Delta c_S + \frac{\Delta c_s + \Delta c_T}{X} (v_T \kappa_{TS} - v_S \kappa_S) \geq - (v_S \mu_S - c_S - v_T \kappa_{TS} (1 - \beta_1) - v_S \kappa_S \beta_1)\), financial barriers in conversion are removed and thus, the equilibrium adoption rate is the same as the case without financially constrained producers, i.e. \(\tilde{\beta}_1^{(\Delta c_S, \Delta c_T)} = \beta_1^{(\Delta c_S, \Delta c_T)} = \beta_1 + \frac{\Delta c_S + \Delta c_T}{X}\),

(ii) Otherwise,

(a) If \(v_S \kappa_S < v_T \kappa_{TS}\), none of the financially constrained producers adopt the sustainable practice in equilibrium, \(\tilde{\beta}_1^{(\Delta c_S, \Delta c_T)} = \min \left(\beta_1^{(\Delta c_S, \Delta c_T)}, 1 - \delta \right)\),
(b) If \( v_S \kappa_S > v_T \kappa_{TS} \), financially constrained producers may adopt the sustainable practice only if all the non-constrained producers adopt it. Thus, in equilibrium, either all of the non-constrained producers as well as a portion of the financially constrained producers adopt the sustainable practice, or only the non-constrained producers (some or all of them) adopt, meaning that 
\[
\tilde{\beta}(\Delta c_S, \Delta c_T) = \min \left( \beta_1(\Delta c_S, \Delta c_T), \max \left( \tilde{\beta}_1, 1 - \delta \right) \right)
\]
where 
\[
\tilde{\beta}_1 = \frac{v_S \mu_S - c_S - v_T \kappa_{TS}}{v_S \kappa_S - v_T \kappa_{TS}}.
\]

**Corollary 3.** Tax-only policy cannot achieve conversion by the financially constrained producers. In fact, if 
\[
\sigma_{TS} > \max \left( \frac{1}{2w \kappa_S + 1} \left( \kappa_T - \mu_T \mu_S + w \kappa_a \left( \frac{v_S \kappa_S - v_T \kappa_{TS}}{v_T \kappa_S - \mu_T \mu_S} \right)^2 - 2 \mu_T \mu_S^2 + \kappa_T \right), \frac{v_S \kappa_S - v_T \kappa_{TS}}{v_T \kappa_S - \mu_T \mu_S} \right),
\]
no policy achieves conversion to the sustainable practice by the financially constrained producers.

Subsidies are essential in providing financially constrained producers with the flexibility to choose sustainable production if it is profitable to do so. To that extent, tax-only policies can only achieve a surge in adoption among the producers that can afford the conversion whilst reducing the profit margins of producers that do not have the financial resources to convert. Furthermore, if the covariance between the yields of the traditional and sustainable practices is high enough, no subsidy-only or hybrid policy can provide incentives for the resource-constrained producers to engage in sustainable production. In this case, the positive impact of the reduction in traditional production on the profits of sustainable production is not enough to overcome the negative impact of increasing competition among adopters. In fact, if the covariance of yields is higher than a threshold, the decline in the cost of the sustainable practice due to subsidies cannot offset the negative effect of increasing competition in the sustainable market, resulting in the failure of the policy in achieving affordability in sustainable production. However, if the condition presented in Corollary 3 does not hold, the policy maker can accomplish sustainable practice adoption by the resource-constrained producers as well as an improvement in social welfare.

**Proposition 13.** Under a zero-expenditure hybrid policy that satisfies 
\[
\Delta c_S + \frac{\Delta c_S + \Delta c_T}{X} (v_T \kappa_{TS} - v_S \kappa_S) \geq - (v_S \mu_S - c_S - v_T \kappa_{TS} (1 - \beta_1) - v_S \kappa_S \beta_1),
\]

(i) If \( \delta \leq 1 - \beta_1 \), social welfare declines,

(ii) Otherwise, social welfare increases if and only if \( \Delta c_S + \Delta c_T < \left( \delta - (1 - \beta_1) \right) X \) where \( \Delta c_S = \frac{1}{2} (-Y - 2 \Delta c_T + \sqrt{Y^2 + 4X \Delta c_T}) \).

Moreover, under any \((\Delta c_S, \Delta c_T)\) policy that satisfies the above condition, government surplus is positive if and only if \( \delta > 1 - \beta_1 \) and \( \Delta c_S + \Delta c_T < \left( \delta - (1 - \beta_1) \right) X \).

If sustainable practice adoption in the absence of government support is low so that even the producers who can afford the conversion choose not to convert, then a zero-expenditure policy results in a decline in social welfare even if the provided support enables the financially constrained
producers to convert as well. That is, as long as the presence of resource-constrained producers does not impact the resulting adoption in the absence of government interventions, social welfare declines under a zero-expenditure policy, consistent with our previous results. However, benefit to producers can be achieved through such a policy, which may be the deriving factor from the perspective of the policy maker. In fact, in developing countries where small farmers struggle with high costs associated with organic farming certification and most of the organic produce is exported to other countries, the government can achieve benefit to producers by eliminating the profit losses due to sustainable production during the transition phase via a zero-expenditure policy. On the other hand, a producer population with a high fraction of financially constrained producers results in a lower adoption rate compared to a population of producers that can afford the conversion, creating an opportunity for the policy maker to increase adoption through a zero-expenditure policy as well as improve the social welfare.

Figure 3 Impact on social welfare and government surplus under a \((\Delta c_S, \Delta c_T)\)-policy in the presence of financially constrained producers with \(\delta > 1 - \beta_1\)

![Diagram](image)

Note. \(v_T = 0.8, \mu_T = 3, \sigma_T = 1, c_T = 0.6, v_S = 1.6, \mu_S = 1, \sigma_S = 0.3, c_S = 1.7, \sigma_{TS} = 0.1, \theta_f = 1.5, \bar{a} = 0.9, \sigma_\alpha = 1, w = 8, M = 12, \delta = 0.95\).

Figure 3a depicts the case in which an improvement in social welfare can be attained using a zero-expenditure hybrid policy. \((\Delta c_S, \Delta c_T)\) policies that lie in region I do not make conversion affordable, thus, failing to enable adoption by the financially constrained producers. Even though policies within region II achieve affordability by offering higher subsidies, social welfare declines as the reduction in profit margins caused by high taxes reduces producers’ profits. Policies residing
in region III, which includes a subset of zero-expenditure policies, achieve sustainable production adoption by the financially constrained producers as well as an improvement in social welfare. Lastly, in region IV, which constitutes a very small subset of policies, even though the financially constrained producers cannot convert, social welfare increases due to the subsidies provided to producers that have the financial resources to undertake adoption. Moreover, as shown in Figure 3b, a positive net return on government spending can be achieved by providing support to financially constrained producers so that they have the option to convert to sustainable production provided that it is more profitable. As the government places more value on social welfare enhancement ($\gamma$ is higher), the set of policies that generate positive government surplus expands such that high-subsidy, low-tax policies are included. Overall, even though zero-expenditure policies cannot improve social welfare in the absence of financially constrained producers or if they constitute a small portion of the producer population, such policies can in fact enhance social welfare if the presence of these producers is a restricting factor on sustainable practice adoption.

## 7. Model Calibration

In this section, we calibrate our model using data on egg production in Denmark. Eggs are considered to be one of the products with highest organic consumption in Denmark, along with dairy products and cereals. Currently, organic egg production amounts to approximately 20% of total egg production. Non-organic egg production dominates the market and includes three different production methods: cage, barn, and free range. We categorize these methods under conventional production when estimating model parameters.

We obtain data on price, yield, and production cost from the Danish Poultry Council Annual Report for the year 2015. The data on kilogram of eggs sold to egg packing for human consumption is obtained from the Denmark Statistics website and used as a proxy for supply. Consumer valuations and the total market size of eggs are estimated using the price (adjusted for inflation) and supply data from 2007 to 2015. The valuations for conventional and organic eggs are presented in Table 2. Since the size of the producer population, i.e. the number of egg-laying hens, is normalized to 1, we take $M = 89.16$ to be the relative size of the consumer population\(^2\). The mean and standard deviation of the yields of conventional and organic egg production are calculated using data from 2007 to 2015. We assume that the expected yield of organic production over this time period corresponds to the long-run expected yield experienced by fast learners given that organic egg production has been practiced since late 1990s. In order to calculate the expected yield during the transition period, it is assumed that fast-learner producers incur 20% improvement in the expected

\(^2\) The number of hens that are used to satisfy the demand in the market in 2015 is calculated as 3.167 million using the kilogram of eggs produced for human consumption and the production yields in that same year.
yield of organic production after the transition phase (Rundgren 2006). Furthermore, organic and conventional yields are found to be positively correlated with a correlation coefficient of 0.97.

<table>
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<td>Expected long-run yield (kg/hen)</td>
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The data on production costs per hen from 2013 to 2015 is used to compute the average cost of conventional and organic production. The cost data disclosed in the Danish Poultry Council Annual Report consists of the feed cost and depreciation per egg-laying-hen, and the average costs are calculated as DKK 134.13 and 214.38 for conventional and organic production, respectively, resulting in the ratio $c_S/c_T$ to be 1.6. However, we adjust this ratio to account for the differences in labor cost of conventional and organic production. Since organic production is labor-intensive, incorporating the labor cost would make a greater impact on the unit cost of organic production (Rundgren 2006, Anderson 2009). As a result, we conduct sensitivity analysis on the relative size of the costs by taking the $c_S/c_T$ ratio as 1.65, 1.7, and 1.75. Lastly, we use $w = 6$, $\bar{\alpha} = 0.7$ and $\sigma_\alpha = 0.1$ as benchmark values and also do sensitivity analysis on these parameters. Setting $w = 6$ reflects that once the transition period is successfully completed, the producer expects to continue engaging in organic farming for a long period of time, which is the case in Denmark due to the country’s emphasis on increasing awareness of organic production. Furthermore, having $\bar{\alpha} = 0.7$ and $\sigma_\alpha = 0.1$ is conforming to the high conversion success rates with low uncertainty in the country.

In practice, farmers have to implement organic farming for a number of years before they can obtain certification and benefit from premium prices. To capture this, we assume that organic products are sold at conventional-product prices during the transition period. Thus, definitions of $X_0$ and $Y_0$ are changed as

$$X_0 = v_T \left( \kappa_S - 2\kappa_{TS} + \kappa_T \right),$$

$$Y_0 = v_T \left( \mu_S - \mu_T + \kappa_T - \kappa_{TS} \right) - c_S + c_T.$$

Using the new definitions of $X_0$ and $Y_0$, the adoption rate in period 1 under no intervention, $\beta_1$, is obtained as in Proposition 2, i.e. $\beta_1 = \frac{Y}{X} = \frac{Y_0 + w\bar{\alpha}Y_1}{X_0 + w\kappa_\alpha X_1}$.

Figure 4 shows the equilibrium adoption rate as a function of $w$, $\bar{\alpha}$, and $\sigma_\alpha$ while keeping two of the parameters fixed at the benchmark value. Adoption rates under different $c_S/c_T$ ratios are $3 \mu_S' = 1.2 \mu_S$ where $\mu_S' = 17.08$ as given in Table 2.
also depicted in order to show the impact of the relative size of labor costs for the two production methods. As can be seen, an increase in the lifespan of organic production or the expected fraction of fast learners (expected success rate) motivates adoption whereas higher uncertainty in the success rate discourages it. From Figure 4b, one can observe that as the difference between the costs of organic and conventional production decreases, the impact of increasing the expected success rate on adoption diminishes. This phenomenon can be explained by the surge in the competition in the sustainable market in that low cost difference incentivizes adoption, resulting in high competition in the sustainable market, thus diminishing the positive effect of high expected success rate on conversion to organic production. Similarly, an increase in the uncertainty in the success rate is more detrimental to adoption when the difference between organic and conventional production costs is low.

Figure 4  Adoption rate as a function of $w$, $\bar{\alpha}$ and $\sigma_\alpha$ under different values of $c_S/c_T$

The adoption rate of organic egg production in Denmark in 2015 is approximately 26%. Under $c_S/c_T = 1.7$, we find the adoption rate under no intervention to be 21.4%. This difference is likely to be due to the subsidies provided for organic egg production. As part of the EU rural development program, the Danish government offers subsidies to farmers for conversion to organic farming based on the area of land converted. The support under this program amounts to €140 per hectare for the first two years of conversion and €13 per hectare for the next three years. Moreover, farmers receive an additional €110 per hectare in support of environmentally friendly farming practices (Willer et al. 2014). However, we do not have data on the acreage of egg production facilities or the average number of hens possessed by them, thus we cannot estimate the amount of subsidy per hen received by organic egg producers. Nevertheless, the Danish government has announced that they aim to double the 2007 adoption rate of organic production by 2020 (The Ministry of Food, Agriculture and Fisheries of Denmark 2015). Applying this target to egg production would mean to increase the adoption rate to 36% since 18% of hens were produced organically in 2007. Next, we will examine policies that can achieve this target adoption level.
Figure 5a shows the set of policies that generate social welfare improvement as well as the policies that can increase the adoption rate from the current benchmark of 21.4% to 36%. One can see that a zero-expenditure policy does not increase social welfare assuming that producers do not have financial constraints that prevent conversion. We find that as the expected success rate decreases, the uncertainty in the success rate increases or the lifespan of organic production decreases, organic production becomes less desirable from the producers’ perspective, resulting in a shrinkage in the set of policies that would result in an overall welfare improvement. Thus, the government has to implement a policy with lower tax or higher subsidy rates in order to preserve the welfare improvement. Same intuition holds as organic production becomes less attractive financially due to an increase in the cost difference between the two production methods as depicted in Figure 5b.

As can be seen in Figure 5a, the government can attain an adoption rate of 36% using a zero-expenditure policy at the loss of social welfare. In fact, Figure 6 shows that such a policy increases producers’ expected profits but reduces consumer surplus. The government can achieve the desired target adoption rate while improving social welfare, in which case at least 4.17% of the organic production cost should be subsidized. A subsidy rate of 4.17% translates into €1.46 million to be spent on subsidies over the course of the transition period. This subsidy rate should be coupled with a tax rate of 2.86% to attain the target adoption rate, resulting in a tax income of €1.04 million. The government can sustain the 36% adoption rate through a policy with lower taxes but in this case, the net government expenditure increases as the subsidy rate should be increased. In fact, if a subsidy-only policy is implemented, 5.84% of the organic production cost should
be subsidized, amounting to a policy expenditure of €2.04 million\(^4\). The policy maker improves producers’ expected profits while achieving the target adoption rate through the aforementioned policies that increase social welfare. However, attaining an adoption rate of 36% would result in a negative impact on consumer surplus under any policy. Note that the expected yield of organic production is less than conventional production, resulting in a reduction in total supply in the market when organic adoption rate increases. Even though the increase in the availability of organic products positively impacts consumers, it does not offset the negative impact of supply reduction when the adoption rate is increased to 36%. As a result, consumers do not benefit from tax/subsidy policies that achieve the target adoption rate. Other types of interventions such as improving organic yields and increasing consumer awareness of organic products are needed in order to ensure benefits to consumers. Improving the yields would remedy the supply reduction problem while increasing consumer awareness would result in higher utility to consumers from the consumption of organic products. Such interventions are sought by the Danish government as well (The Ministry of Food, Agriculture and Fisheries of Denmark 2015). It may be possible to benefit both producers and consumers while achieving the target adoption rate by supporting monetary incentives (taxes and subsidies) with efforts in improving the yield and consumer awareness.

8. Conclusion

Increasing environmental and health concerns have drawn attention to sustainable agricultural production methods such as organic farming. Even though sustainable production is often associated with premium prices, high costs and low yields may undermine its profitability, causing a

\(^4\) 1 DKK = 0.13 EUR.
resistance from the producers in converting to sustainable practices. To that extent, policy makers often implement various interventions in order to encourage the conversion to sustainable practices. In this paper, we investigate the effectiveness of taxes on the inputs of the traditional practice, subsidies on the sustainable practice and a hybrid policy that incorporates both, in terms of their impact on the adoption rate, the benefit to producers and consumers as well as the government expenditure and surplus.

We find that a zero-expenditure policy causes reduction in social welfare, meaning that it may benefit either the producers or consumers but not both. Furthermore, even though the tax-only policy increases the adoption rate, it cannot improve social welfare compared to the no-intervention case. One could design positive-expenditure policies (subsidy-only or hybrid) that benefit both the producers and consumers, but in this case, the net government surplus is always negative. An important finding is that even though a hybrid policy achieves higher consumer surplus under some conditions, a subsidy-only policy always outperforms the corresponding hybrid policy with the same expenditure or same unit subsidy in terms of attaining higher social welfare. However, the converse is true in achieving a higher adoption rate. Thus, the policy objective, whether it is to improve the environmental conditions, benefit the producers or consumers, determines the intervention type that is most effective.

Additionally, we study the case with financially constrained producers that cannot afford the profit losses caused by the sustainable practice during the low-yield transition phase. In this case, if a high portion of the producer population consists of financially constrained producers, i.e. lack of financial resources restricts sustainable production adoption, the policy maker may achieve an increase in social welfare using a zero-expenditure policy that serves as a support for producers to overcome the financial barriers. Finally, we calibrate our model using data on conventional and organic egg production in Denmark. Given the Danish government’s goal of doubling organic adoption by 2020, we investigate the policies that can achieve this goal for organic egg production. It is found that the government should at least subsidize 4.17% of the organic production cost in order to generate a positive impact on social welfare while reaching the desired adoption rate. Producers benefit from policies that improve social welfare as these policies consist of high subsidy and low tax rates. However, consumer surplus decreases as adoption rate is doubled due to low organic yields. Hence, policies that involve monetary transfers to producers such as taxes and subsidies should be coupled with yield-enhancing efforts and efforts in increasing consumer awareness of organic products in order to benefit both sides of the market while achieving the target adoption rate.
Appendix

Proof of Proposition 1.

There are four types of scenarios that can constitute the equilibrium in the continuation period as listed below. Out of the producers that adopt the sustainable practice in period 1,

I. only some portion of the fast-learners continue using the sustainable practice in period 2 while the remaining fast learners and all of the slow learners revert to the traditional practice,

II. all of the fast learners and some portion of the slow learners continue using the sustainable practice in period 2 while the remaining slow learners revert to the traditional practice,

III. all of the fast learners continue using the sustainable practice in period 2 while all of the slow learners revert to the traditional practice,

IV. all of the slow learners continue using the sustainable practice in period 2 while all of the fast learners revert to the traditional practice.

Case I : For this to be equilibrium, it has to be that \( \pi_{T2|\alpha} = \pi_{S2|\alpha} \) since the fast learners are indifferent between continuing with the sustainable practice and reverting to the traditional practice. The indifference condition in period 1

\[
\pi_T + wE_{\theta} [\pi_{T2|\alpha}] = \pi_S + wE_{\theta} [\alpha\pi_{S2|\alpha} + (1-\alpha)\pi_{T2|\alpha}]
\]

reduces to

\[
\pi_T + wE_{\theta} [\pi_{T2|\alpha}] = \pi_S + wE_{\theta} [\alpha\pi_{T2|\alpha} + (1-\alpha)\pi_{T2|\alpha}].
\]

Thus, the equilibrium adoption rate in period 1 is given by \( \pi_T = \pi_S \). But this does not hold as \( \pi_T > 0 \) due to the assumptions \( v_T\mu_T - c_T - v_T\kappa_T > 0 \) and \( v_T\mu_T - c_T - v_T\kappa_T^f > 0 \), and \( \pi_S < 0 \) since \( v_S\mu_S < c_S \).

Case II : For this to be equilibrium, it has to be that \( \pi_{T2|\alpha} = \pi_{S2|\alpha}^f \) since the slow learners are indifferent between continuing with the sustainable practice and reverting to the traditional practice. However, since \( \theta_s = 0, \pi_{S2|\alpha} < 0 \) whereas \( \pi_{T2|\alpha} > 0 \) \( \forall \alpha \in [0,1] \) due to the assumptions \( v_T\mu_T - c_T - v_T\kappa_T > 0 \) and \( v_T\mu_T - c_T - v_T\kappa_T^f > 0 \). Hence, there exist a profitable deviation for slow learners in the form of reverting to the traditional practice.

Case III : This is a valid equilibrium as long as the solution to (9) satisfies (6) and (7).

Case IV : In this case, there exists a profitable deviation for fast learners in the form of using the sustainable practice as \( \theta_f > \theta_s \). Thus, this cannot be the equilibrium.

Hence, the unique equilibrium is given by (III).
Proof of Proposition 2.

Given (1), (2), (3), and (4), it is straightforward to calculate the solution to (9), which is given by
\[
\beta_1 = \frac{(v_s\mu_S - c_S - v_T\mu_T + c_T + v_T\kappa_T - v_T\kappa_{TS}) + w\alpha (v_s\mu_S' - c_S - v_T\mu_T + c_T + v_T\kappa_T - v_T\kappa_{TS}')}{v_s\kappa_S - 2v_T\kappa_{TS} + v_T\kappa_T + w\kappa (v_s\kappa_S' - 2v_T\kappa_{TS}' + v_T\kappa_T')}
\]
\[
= \frac{Y_0 + w\alpha Y_1}{X_0 + w\kappa X_1 - Y}.
\]

Before proving that \(\beta_1\) satisfies the condition given in (8), we need to show that \(X_0 > 0\) and \(X_1 > 0\).
\[
X_0 = v_s (\mu_S^2 + \sigma_S^2) - 2v_T (\sigma_{TS} + \mu_S\mu_T) + v_T (\mu_T^2 + \sigma_T^2)
\]
\[
> v_T (\mu_S - \mu_T)^2 + v_T (\sigma_S^2 - 2\sigma_{TS} + \sigma_T^2) \quad \text{(since } v_s > v_T)\]
\[
> v_T (\mu_S - \mu_T)^2 + v_T (\sigma_S + \sigma_T)^2 \quad \text{(since } \sigma_{TS} < \sigma_S \sigma_T)\]
\[
> 0.
\]

Similarly, one can show that \(X_1 > 0\). Moreover, \(Y_0 < 0\) since \(v_s\mu_S < c_S\) and \(v_T\mu_T - c_T - v_T\kappa_T > 0\). Due to (10), we have \(Y > 0\), so it has to be that \(Y_1 > 0\). Now, (8) can be simplified as
\[
\bar{\alpha} \beta_1 X_1 \leq Y_1
\]
\[
\iff \bar{\alpha} \frac{Y_0 + w\alpha Y_1}{X_0 + w\kappa X_1} X_1 \leq Y_1
\]
\[
\iff \bar{\alpha} Y_0 X_1 + w\alpha^2 Y_1 X_1 \leq X_0 Y_1 + w\kappa X_1 Y_1 \quad \text{(since } X_0 > 0 \text{ and } X_1 > 0)\]
\[
\iff \bar{\alpha} Y_0 X_1 \leq (X_0 + w\sigma_X^2 X_1) Y_1.
\]

where the last inequality holds since the left hand side is negative whereas the right hand side is positive. Lastly, \(\beta_2 = \alpha \beta_1\) since only the fast learners continue using the sustainable practice in period 2, resulting in \(E_\alpha [\beta_2] = \bar{\alpha} \beta_1\), concluding the proposition.

\[\square\]

Proof of Corollary 1.

It is straightforward to see that \(\beta_1\) increases in \(c_T\) and decreases in \(c_S\) and \(\sigma_\alpha\). We will calculate the partial derivatives for the rest of the comparative statistics.
\[
\frac{\partial \beta_1}{\partial w} = \frac{\bar{\alpha} Y_1 X - \kappa_\alpha Y_1}{X^2} Y = \frac{\bar{\alpha} Y_1 (X_0 + w\kappa X_1) - \kappa_\alpha X_1 (Y_0 + w\alpha Y_1)}{X^2} Y = \frac{\bar{\alpha} Y_1 X_0 - \kappa_\alpha X_1 Y_0}{X^2} > 0
\]

since \(Y_0\) is negative whereas \(X_0, X_1,\) and \(Y_1\) are positive as shown in the proof of Proposition 2.
\[
\frac{\partial \beta_1}{\partial \bar{\alpha}} = \frac{w (XY_1 - 2\bar{\alpha}X_1)}{X^2}
\]
and
\[
\frac{\partial^2 \beta_1}{\partial \bar{\alpha}^2} = -\frac{2w X_1 (XY + 2w\bar{\alpha} (XY_1 - 2\bar{\alpha}X_1))}{X^3}
\]

where \(\bar{\alpha}\) is given by \(XY_1 - 2\bar{\alpha}X_1 = 0\). Thus, \(\beta_1\) increasing in \(\bar{\alpha}\) if \(\bar{\alpha} < \bar{\alpha}\) (and concave in this region), decreasing otherwise.

Moreover,
\[
\frac{\partial (\bar{\alpha}\beta_1)}{\partial \bar{\alpha}} = \frac{XY + w\bar{\alpha} (XY_1 - 2\bar{\alpha}X_1)}{X^2} Y \geq \frac{XY + w\bar{\alpha} (\bar{\alpha}X_1 Y - 2\bar{\alpha}X_1)}{X^2} Y = \frac{Y (X_0 + w\sigma_X^2 X_1)}{X^2} > 0
\]

where the first inequality is due to condition (8) together with \(\beta_1 = \frac{Y}{X}\).
Proof of Proposition 3.

Under a zero-expenditure policy,
\[
\zeta^{(\Delta c_S, \Delta c_T)} = \Delta c_S \beta (\Delta c_S, \Delta c_T) - \Delta c_T \left(1 - \beta (\Delta c_S, \Delta c_T)\right)
\]
\[
= \Delta c_S \beta - \Delta c_T \left(1 - \beta\right) + \frac{(\Delta c_S + \Delta c_T)^2}{X}
\]
\[
= 0.
\]
Thus, \(\Delta c_S \beta - \Delta c_T (1 - \beta) = -\frac{(\Delta c_S + \Delta c_T)^2}{X} < 0\). Using (16), we have \(\Delta \Pi_{SW} = \frac{1}{2} (\Delta c_S \beta - \Delta c_T (1 - \beta)) < 0\) under a zero-expenditure policy, proving the proposition.

□

Proof of Proposition 4.

Under a zero-expenditure policy, \(\zeta^{(\Delta c_S, \Delta c_T)} = 0\), we have \((\Delta c_S + \Delta c_T) \beta (\Delta c_S, \Delta c_T) = \Delta c_T\). Using this and (12), one can write
\[
\Delta \Pi_P = (\Delta c_S + \Delta c_T) \left(\frac{Z}{X} - \beta (\Delta c_S, \Delta c_T)\right)
\]
\[
= (\Delta c_S + \Delta c_T) \left(\frac{Z}{X} - \beta - \frac{\Delta c_S + \Delta c_T}{X}\right).
\]
Thus, the expected profits of producers increase if and only if \(\Delta c_S + \Delta c_T < Z - Y\). Moreover, using (13), one can conclude that the consumer surplus increases if and only if \(\Delta c_S + \Delta c_T > 2(Z - Y)\), proving the proposition.

□

Proof of Proposition 5.

Using (14), one can see that the change in social welfare under a subsidy-only policy reduces to \(\Delta \Pi_{SW} = \frac{1}{2} \Delta c_S (\beta + \beta (\Delta c_S)) > 0\) whereas the social welfare under a tax-only policy is given by \(\Delta \Pi_{SW} = \Delta c_T \left(\frac{\beta + \beta (\Delta c_T)}{2} - 1\right) < 0\). On the other hand, under a hybrid policy,
\[
\Delta \Pi_{SW} = \frac{1}{2} (\Delta c_S + \Delta c_T) \left(2 \beta + \frac{\Delta c_S + \Delta c_T}{X}\right) - \Delta c_T
\]
\[
= \frac{(\Delta c_S + \Delta c_T)^2}{2X} + (\Delta c_S + \Delta c_T) \frac{Y}{X} - \Delta c_T
\]
\[
= \frac{(\Delta c_S + \Delta c_T)^2 + 2Y \Delta c_S - 2X Y \Delta c_T}{2X}
\]
which is positive if and only if the numerator is positive as \(X > 0\).

□

Proof of Proposition 6.

Using (12) and (13), one can deduce that
\[
\Delta \Pi_P - \Delta \Pi_C = (\Delta c_S + \Delta c_T) \left(\frac{2Z - Y}{X} - \frac{\Delta c_S + \Delta c_T}{2X}\right) - \Delta c_T
\]
\[
= -\frac{(\Delta c_S + \Delta c_T)^2}{2X} + 2(\Delta c_S + \Delta c_T) (2Z - Y) - 2X \Delta c_T.
\]
Thus, if \(2Z < Y\), \(\Delta \Pi_P < \Delta \Pi_C\). Otherwise, \(\Delta \Pi_P > \Delta \Pi_C\) if and only if \((\Delta c_S + \Delta c_T)^2 - 2(\Delta c_S + \Delta c_T) (2Z - Y) + 2X \Delta c_T < 0\), proving the proposition.

□
Proof of Corollary 2.

Given that

\[ 2Z - Y = \nu_T (\kappa_T - \kappa_{TS} + \bar{\omega} (\kappa_T - \kappa_{TS}^f)) - (\nu_S \mu_S - c_S - \nu_T \mu_T + c_T) - \bar{\omega} (\nu_S \mu_S^f - c_S - \nu_T \mu_T + c_T) \]

and

\[ X = \nu_S \kappa_S - 2 \nu_T \kappa_{TS} + \nu_T \kappa_T + \bar{\omega} \nu_S \kappa_S^f - 2 \nu_T \kappa_{TS}^f + \nu_T \kappa_T, \]

it is straightforward to see that \( 2Z - Y \) increases as \( c_S \) increases or \( c_T \) decreases whereas \( X \) does not depend on any of the cost parameters. Thus, the condition \( (\Delta c_S + \Delta c_T)^2 - 2 (\Delta c_S + \Delta c_T) (2Z - Y) + 2X \Delta c_T < 0 \)

holds for a larger set of policies as \( c_S \) increases or \( c_T \) decreases. Moreover, \( X \) is increasing in \( v_S, \sigma_S \) and \( \sigma_a \) whereas \( 2Z - Y \) is decreasing in \( v_S \), and does not depend on \( \sigma_S \) or \( \sigma_a \), thus proving the result.

\[ \square \]

Proof of Proposition 7.

Using (16), we can write

\[ \Delta \Pi_G = \frac{1}{2} (\Delta c_S \beta_1 - \Delta c_T (1 - \beta_1) - \zeta (\Delta c_S, \Delta c_T)) \]

\[ = \frac{1}{2} (\Delta c_S + \Delta c_T) (\beta_1 - \beta_1 (\Delta c_S, \Delta c_T)) \]

\[ = - \frac{(\Delta c_S + \Delta c_T)^2}{2X} < 0 \]

\( X \) is increasing in \( \bar{\omega}, \sigma_a \) and \( w \), and decreasing in \( \sigma_{TS} \), proving the result.

\[ \square \]

Proof of Proposition 8.

Since \( \beta_1 (\Delta c_S, \Delta c_T) < 1 \), i.e. \( \Delta c_S + \Delta c_T < X - Y \), we have \( \beta_1 (\Delta c_S) < 1 \). Using (14), one can deduce that

\[ \Delta \Pi_{SW}^{(\Delta c_S, \Delta c_T)} - \Delta \Pi_{SW}^{(\Delta c_S, \Delta c_T)} = \frac{1}{2} \Delta c_S \left[ \beta_1 + \beta_1 (\Delta c_S) \right] - \frac{1}{2} (\Delta c_S + \Delta c_T) \left[ \beta_1 + \beta_1 (\Delta c_S, \Delta c_T) \right] + \Delta c_T \]

\[ = \frac{1}{2} \Delta c_S \left[ \beta_1 (\Delta c_S) - \beta_1 (\Delta c_S, \Delta c_T) \right] - \frac{1}{2} \Delta c_T \left[ \beta_1 + \beta_1 (\Delta c_S, \Delta c_T) \right] + \Delta c_T \]

\[ = \frac{\Delta c_T}{X} \left( X - \Delta c_S - \frac{\Delta c_T}{2} \right) > 0. \]

where the last inequality holds since \( \Delta c_S + \Delta c_T < X - Y \). Moreover, using (16), we can write,

\[ \Delta \Pi_G^{(\Delta c_S, \Delta c_T)} - \Delta \Pi_G^{(\Delta c_S, \Delta c_T)} = \frac{1}{2} \left( \Delta c_S \beta_1 - \zeta (\Delta c_S) \right) - \frac{1}{2} (\Delta c_S \beta_1 - \Delta c_T (1 - \beta_1) - \zeta (\Delta c_S, \Delta c_T)) \]

\[ = \frac{1}{2} \Delta c_S \left[ \beta_1 - \beta_1 (\Delta c_S) \right] - \frac{1}{2} (\Delta c_S + \Delta c_T) \left[ \beta_1 - \beta_1 (\Delta c_S, \Delta c_T) \right] \]

\[ = \frac{1}{2} \left( \Delta c_S \left[ \beta_1 (\Delta c_S, \Delta c_T) - \beta_1 (\Delta c_S) \right] + \Delta c_T \left( \beta_1 (\Delta c_S, \Delta c_T) - \beta_1 \right) \right) > 0. \]
Thus,
\[ \zeta(\Delta s) - \zeta(\Delta s_1, \Delta c_T) = \Delta c_s \beta_1(\Delta s) - \left( \Delta c_s \beta_1(\Delta s, \Delta c_T) - \Delta c_T \left( 1 - \beta_1(\Delta s, \Delta c_T) \right) \right) \]
\[ = -\Delta c_s \frac{\Delta c_T}{X} - \Delta c_T \beta_1 - \Delta c_s + \Delta c_T \frac{\Delta c_s + \Delta c_T}{X} + \Delta c_T \]
\[ = \frac{\Delta c_T}{X} (X - Y - 2\Delta c_s - \Delta c_T) \]

resulting in \( \zeta(\Delta s) > \zeta(\Delta s_1, \Delta c_T) \) if and only if \( 2\Delta c_s + \Delta c_T < X - Y \).

\[ \square \]

**Proof of Proposition 9.**

Let \( \overline{\Delta c}_s \) denote the unit subsidy under the subsidy-only policy. Given that \( \beta_1(\Delta c_s, \Delta c_T) < 1 \), it has to be that \( \beta_1(\overline{\Delta c}_s) < 1 \), i.e. \( \overline{\Delta c}_s < X - Y \), since otherwise, expenditure equivalence cannot be satisfied. As the total expenditure is the same under the hybrid and subsidy-only policies, we have

\[ \overline{\Delta c}_s \beta_1(\overline{\Delta c}_s) = \Delta c_s \beta_1(\Delta c_s, \Delta c_T) - \Delta c_T \left( 1 - \beta_1(\Delta c_s, \Delta c_T) \right) \]
\[ \iff \overline{\Delta c}_s \left( \beta_1 + \frac{\Delta c_s}{X} \right) = \beta_1 (\Delta c_s + \Delta c_T) + \frac{(\Delta c_s + \Delta c_T)^2}{X} - \Delta c_T \]
\[ \iff \beta_1 (\Delta c_s + \Delta c_T - \overline{\Delta c}_s) + \frac{(\Delta c_s + \Delta c_T - \overline{\Delta c}_s)(\Delta c_s + \Delta c_T + \overline{\Delta c}_s)}{X} = \Delta c_T \]
\[ \iff \Delta c_s + \Delta c_T - \overline{\Delta c}_s = \frac{\Delta c_T}{\beta_1 + \frac{\Delta c_s + \Delta c_T + \overline{\Delta c}_s}{X}} > 0. \]

Thus, \( \overline{\Delta c}_s < \Delta c_s + \Delta c_T \), meaning that \( \beta_1(\overline{\Delta c}_s) < \beta_1(\Delta (\Delta c_s, \Delta c_T)) \).

Moreover, using (14), we have

\[ \Delta \Pi_{SW}^{(\overline{\Delta c}_s)} - \Delta \Pi_{SW}^{(\Delta c_s, \Delta c_T)} = \frac{1}{2} \left( \overline{\Delta c}_s \left( \beta_1 + \beta_1(\overline{\Delta c}_s) \right) - (\Delta c_s + \Delta c_T) \left( \beta_1 + \beta_1(\Delta c_s, \Delta c_T) \right) \right) + \Delta c_T \]
\[ = \frac{1}{2} \left( -\beta_1 (\Delta c_s + \Delta c_T - \overline{\Delta c}_s) + \overline{\Delta c}_s \beta_1(\overline{\Delta c}_s) - (\Delta c_s + \Delta c_T) \beta_1(\Delta c_s, \Delta c_T) \right) + \Delta c_T \]
\[ = \frac{1}{2} \Delta c_T \left( 1 - \frac{\beta_1}{\beta_1 + \frac{\Delta c_s + \Delta c_T + \overline{\Delta c}_s}{X}} \right) > 0. \]

\[ \square \]

**Proof of Proposition 10.**

Using (13), we get

\[ \Delta \Pi_C^{(\overline{\Delta c}_s)} - \Delta \Pi_C^{(\Delta c_s, \Delta c_T)} = \frac{1}{2} \overline{\Delta c}_s \left( \beta_1 + \beta_1(\overline{\Delta c}_s) - \frac{2Z}{X} \right) - \frac{1}{2} (\Delta c_s + \Delta c_T) \left( \beta_1 + \beta_1(\Delta c_s, \Delta c_T) - \frac{2Z}{X} \right) \]
\[ = \left( \beta_1 - \frac{Z}{X} \right) (\overline{\Delta c}_s - \Delta c_s - \Delta c_T) + \overline{\Delta c}_s^2 \frac{\Delta c_T}{2X} - \frac{(\Delta c_s + \Delta c_T)^2}{2X} \]
\[ = \overline{\Delta c}_s - \Delta c_s - \Delta c_T \frac{Y - Z + \Delta c_s + \Delta c_T + \overline{\Delta c}_s}{2X}. \]
As shown in the proof of Proposition 9, $\Delta c_S < \Delta c_S + \Delta c_T$. Thus, if $Y > Z$, i.e. $w \alpha \left( v_S \mu'_S - c_S - v_T \mu_T + c_T \right) > v_T \mu_T - c_T - v_S \mu_S + c_S$, $\Delta \Pi_C^{(\Delta S)} < \Delta \Pi_C^{(\Delta c_T, \Delta c_T)}$. Moreover, using (12), we have,

$$
\Delta \Pi_P^{(\Delta S)} - \Delta \Pi_P^{(\Delta c_S, \Delta c_T)} = \left( \Delta c_S - \Delta c_S - \Delta c_T \right) \frac{Z}{X} + \Delta c_T
$$

$$
= \Delta c_T \left( 1 - \frac{Z/X}{Y + \Delta c_S + \Delta c_T + \Delta c_S} \right) \quad \text{(due to expenditure equivalence)}
$$

$$
= \Delta c_T \left( \frac{Y - Z + \Delta c_S + \Delta c_T + \Delta c_S}{Y + \Delta c_S + \Delta c_T + \Delta c_S} \right).
$$

Hence, if $Y > Z$, $\Delta \Pi_P^{(\Delta S)} > \Delta \Pi_P^{(\Delta c_S, \Delta c_T)}$, proving the proposition.

**Proof of Proposition 11.**

If $\delta \leq 1 - \beta_1$, the solution to the indifferece condition presented in (9) is given by $\tilde{\beta}_1 = \beta_1 = \frac{\gamma}{\tilde{Y}}$, meaning that some portion of the producers that are not financially constrained choose to use the traditional practice instead of adopting the sustainable practice. If $\delta > 1 - \beta_1$, the presence of financially constrained producers restricts the adoption rate $\tilde{\beta}_1$ from reaching the adoption rate in the absence of financial constraints, $\beta_1$, meaning that $\tilde{\beta}_1 < \beta_1$. Note that for adoption rate that is less than $\beta_1 = \frac{\gamma}{\tilde{Y}}$, the right hand side of (9), $\pi_{S1} + w E_a [\alpha \pi_{S2} (\alpha + (1 - \alpha) \pi_{T2}) \alpha]$, is greater than the left hand side, $\pi_{T1} + w E_a [\pi_{T2} \alpha]$. Thus, a profitable deviation to the sustainable practice exists if $\tilde{\beta}_1 < 1 - \delta$. Also, it cannot be that $\tilde{\beta}_1 > 1 - \delta$ since the financially constrained producers cannot afford the conversion. Thus, we have $\tilde{\beta}_1 = 1 - \delta$, proving the proposition.

**Proof of Proposition 12.**

Given that $\beta_1^{(\Delta c_S, \Delta c_T)} = \beta_1 + \frac{\Delta c_S + \Delta c_T}{X}$, if the $(\Delta c_S, \Delta c_T)$ policy is such that

$$
\pi_{S1}^{(\Delta c_S, \Delta c_T)} = v_S \mu_S - c_S - \Delta c_S - \nu_T \kappa_{TS} \left( 1 - \beta_1^{(\Delta c_S, \Delta c_T)} \right) - v_S \kappa_S \beta_1^{(\Delta c_S, \Delta c_T)}
$$

$$
= v_S \mu_S - c_S - \nu_T \kappa_{TS} (1 - \beta_1) - v_S \kappa_S \beta_1 + \Delta c_S + \frac{\Delta c_S + \Delta c_T}{X} \left( \nu_T \kappa_{TS} - v_S \kappa_S \right)
$$

is greater than or equal to zero, then any producer can convert to the sustainable practice, meaning that the problem reduces to the case without the financially constrained producers. Thus, $\beta_1^{(\Delta c_S, \Delta c_T)} = \beta_1^{(\Delta c_S, \Delta c_T)}$.

On the other hand, if $\Delta c_S + \frac{\Delta c_S + \Delta c_T}{X} (\nu_T \kappa_{TS} - v_S \kappa_S) < -(v_S \mu_S - c_S - v_T \kappa_{TS} (1 - \beta_1) - v_S \kappa_S \beta_1)$, we will investigate the following two cases.

**Case I:** If $v_S \kappa_S < \nu_T \kappa_{TS}$:

If $\beta_1^{(\Delta c_S, \Delta c_T)} < 1 - \delta$, then in equilibrium, none of the financially constrained producers and some portion of the non-constrained producers do not adopt the sustainable practice and $\beta_1^{(\Delta c_S, \Delta c_T)} = \beta_1^{(\Delta c_S, \Delta c_T)}$. If $\beta_1^{(\Delta c_S, \Delta c_T)} \geq 1 - \delta$, the equilibrium adoption rate cannot be $\beta_1^{(\Delta c_S, \Delta c_T)}$ as the financially constrained producers cannot afford to convert to the sustainable practice. In this case, the equilibrium adoption rate is $1 - \delta$ and only the non-constrained producers adopt the sustainable practice. Note that there is no profitable deviation to the traditional practice from the perspective of non-constrained producers as the right hand side of (9) is in fact greater than or equal to the left hand side since $\beta_1^{(\Delta c_S, \Delta c_T)} \geq 1 - \delta$. Also, none of the
financially-constrained producers can deviate to the sustainable practice since the profits in period 1 from the sustainable practice is negative. Thus, we have $\beta_1(\Delta c_s, \Delta c_T) = \min\left(\beta_1(\Delta c_s, \Delta c_T), 1-\delta \right)$.

**Case II**: If $v_S \kappa_S > v_T \kappa_{TS}$.

If $\beta_1(\Delta c_s, \Delta c_T) < 1-\delta$, then $\beta_1(\Delta c_s, \Delta c_T) = \beta_1(\Delta c_s, \Delta c_T)$ by the same reasoning as above. If $\beta_1(\Delta c_s, \Delta c_T) \geq 1-\delta$, $\exists 3\beta_1$ such that $v_S \mu_S - c_S + \Delta c_s - v_T \kappa_{TS} (1-3\beta_1) - v_S \kappa_S 3\beta_1$ is given by $3\beta_1 = \frac{v_S \mu_S - c_S - v_T \kappa_{TS} + \Delta c_s}{v_S \kappa_S - v_T \kappa_{TS}}$. Note that $3\beta_1 < \beta_1(\Delta c_s, \Delta c_T)$. Now, if $3\beta_1 > 1-\delta$, then the equilibrium adoption rate is $3\beta_1$ and all the non-constrained producers convert to the sustainable practice. But in this case, the financially-constrained producers can deviate to the sustainable practice since the profits in period 1 from the sustainable practice is negative, so the financially constrained producers cannot afford conversion to the sustainable practice. Note that there is no profitable deviation since the expected profit from the sustainable practice in period 1 is zero and the total expected profit from the sustainable practice (the right hand side of (9)) exceeds that of the traditional practice (the left hand side of (9)). If $3\beta_1 < 1-\delta$, the equilibrium adoption rate is $3\beta_1$ and all the financially-constrained producers adopt the sustainable practice. Overall, we have $\beta_1(\Delta c_s, \Delta c_T) = \min\left(\beta_1(\Delta c_s, \Delta c_T), \max\left(3\beta_1, 1-\delta \right) \right)$.

**Proof of Corollary 3.**

Under a tax-only policy, $\pi_{s_1}^{(c_T)} = v_S \mu_S - c_S - v_T \kappa_{TS} (1-3\beta_1) - v_S \kappa_S 3\beta_1 < 0$, $\forall \Delta c_T \geq 0$, so the financially constrained producers cannot afford conversion to the sustainable practice.

For a $(\Delta c_s, \Delta c_T)$ policy, if

$$X + v_T \kappa_{TS} - v_S \kappa_S = -v_T \kappa_{TS} + v_T \kappa_T + w \kappa_S (v_S \kappa_S^T - 2v_T \kappa_{TS} + v_T \kappa_T) < 0,$$

i.e. $\sigma_{TS} > \frac{1}{w \kappa_S + 1} \left(\kappa_T - w \kappa_S \left(\frac{v_S \kappa_S}{v_T} - 2\kappa_T + \kappa_T\right)\right)$, then $\pi_{s_1}^{(\Delta c_s, \Delta c_T)} < 0$. Moreover, if $v_S \kappa_S < v_T \kappa_{TS}$, i.e. $\sigma_{TS} > \frac{v_S \kappa_S}{v_T} \kappa_S - \mu_T \mu_S$, then the equilibrium (given in Case I above) always entails a fraction of financially-constrained producers’ adopting the sustainable practice and the financially constrained producers’ not converting to the sustainable practice under any policy.

**Proof of Proposition 13.**

Note that $\Delta c_s + \frac{\Delta c_s + \Delta c_T}{X}(v_T \kappa_{TS} - v_S \kappa_S) \geq -(v_S \mu_S - c_S - v_T \kappa_{TS} (1-\beta_1) - v_S \kappa_S \beta_1)$ means that $\pi_{s_1}^{(\Delta c_s, \Delta c_T)} \geq 0$, so under the intervention, financially constrained producers can also afford the conversion, resulting in $\beta_1^{(\Delta c_s, \Delta c_T)} = \beta_1(\Delta c_s, \Delta c_T)$. In this case, if $\delta \leq 1 - \beta_1$, $3\beta_1 = \beta_1$. We have shown before that the zero-expenditure policies result in a reduction in social welfare given the adoption rates $\beta_1$ and $\beta_1^{(\Delta c_s, \Delta c_T)}$ under no intervention and a $(\Delta c_s, \Delta c_T)$ policy, respectively. Also, as shown before, the government surplus is always negative.

Now, if $\delta > 1 - \beta_1$, $3\beta_1 = 1-\delta$. In this case, the change in social welfare is given as follows.

$$\Delta \Pi_{SW}^{(\Delta c_s, \Delta c_T)} = \frac{1}{2} \left(\beta_1(\Delta c_s, \Delta c_T)^2 + (1-\delta)^2 X - 2Y (1-\delta) - 2\Delta c_T\right)$$

$$= (\beta_1 - (1-\delta))^2 X \left(\frac{\Delta c_s \beta_1 - \Delta c_T (1-\beta_1)}{\zeta(\Delta c_s, \Delta c_T) - \frac{(\Delta c_s + \Delta c_T)^2}{X}}\right)$$
\[
= (\beta_1 - (1 - \delta))^2 \frac{X}{2} - (\Delta c_S + \Delta c_T)^2 \quad \text{(since } \zeta(\Delta c_S, \Delta c_T) = 0) \\
= \frac{1}{2X} ((\beta_1 - (1 - \delta)) X - \Delta c_S - \Delta c_T) ((\beta_1 - (1 - \delta)) X + \Delta c_S + \Delta c_T). \\
\]

So, \( \Delta \Pi_{SW}^{(\Delta c_S, \Delta c_T)} > 0 \) if and only if \( \Delta c_S + \Delta c_T < (\beta_1 - (1 - \delta)) X \).

Also, from the above calculation, note that

\[
\Delta \Pi_G^{(\Delta c_S, \Delta c_T)} = \Delta \Pi_{SW}^{(\Delta c_S, \Delta c_T)} - \zeta(\Delta c_S, \Delta c_T) = (\beta_1 - (1 - \delta))^2 \frac{X}{2} - (\Delta c_S + \Delta c_T)^2, \\
\]

proving the proposition.

\[\square\]

References

American Economic Review. 102(1) 131–166.


