Regulatory integration and transregional corporations' new investments

Abstract

To evaluate the economic implications of regulatory heterogeneity, we compare three regimes—harmonised regulation (HR), individual regulation (IR), and optional harmonised regulation (OHR). We evaluate the number of regions transregional firms should operate in the three regimes by implementing a real option model with ex-ante regulation and ex-post liability. We conclude that under OHR, there is a threshold number of regions firms can follow HR, and firms running a business below the threshold are better off following IR. We find the increase of regulatory integration will have different economic impacts on firms of different sizes. Furthermore, the threshold will decrease when considering a future option of possible expansion to more regions. At last, taking the EU fertilizer regulation as an example, we perform a Monte Carlo simulation regarding the OHR to explain our model.

Keywords

Regulatory harmonisation, approval costs, fertiliser regulation, transregional corporations, new investment.

1 Introduction

The growing interdependence of the world's economies has promoted international trade and investment among multinational companies in the past decades, and these economic activities are regulated by local governments. Different countries or regions commonly have different regulatory regimes or regulatory heterogeneity, which could be due to numerous reasons, such as the diversity of cultural norms, environmental standards and safety issues, and for various purposes, such as protecting the local economy from risks or supporting local corporations in competitions (Alan Sykes, 1999).

For companies running a business in many regions, i.e., transregional corporations, regulatory heterogeneity is a crucial factor that can affect their economic benefits and investment decisions. The regions in this paper refer to areas with regulatory heterogeneity, which could be member states in the European Union (EU), provinces in China or states in the United States (US). When starting a new business or investing in a new product, transregional corporations must consider the regulatory heterogeneity of different regions and consider how to maximise their profits.

In this paper, we compare three regulatory regimes. The first is harmonised regulation (HR). For HR, all regions share mandatory harmonized regulation to allow products to be freely circulated with no interregional barriers. Only products following HR could be sold lawfully in the whole area. One example is the mandatory national standards in China. Products only meeting mandatory national standards could be sold in China (Suttmeier et al., 2009).

The second is individual regulation (IR), where IR of each region exists, and all regions have mandatory IR because no HR exists. In this case, firms must apply for each region's approval to make products lawfully sold. One example is the renewable portfolio standards (RPS) in the US. RPS requires utility companies to source a certain amount of the energy they generate or sell from renewable sources, such as wind and solar energy, and it can vary widely from state to state (Wiser et al., 2007). Firms must meet that state's standard to allow products to be lawfully circulated there.

The last one is optional harmonised regulation (OHR), where both HR and IR exist. Products meeting HR could be sold in all regions or meeting specific IR could be sold in specific regions. One example is the Fertilizer Products Regulation 2019/1009 (FPR 2019/1009) of the EU (European Union, 2019b). FPR 2019/1009 takes effect on July 16, 2022. Contrary to most other products' harmonisation measures in EU law, FPR 2019/1009 follows OHR. Box 1 provides a detailed explanation of the OHR of FPR 2019/1009.

Box 1 Example of EU FPR 2019/1009

As the circular economy, green economy, and bioeconomy have gained increasing attention, a growing influence has been presented on the EU fertiliser legislation (Klaus and Meier, 2020; Wesseler and von Braun, 2017). Fertilisers are vital inputs for agriculture; however, the fertiliser industry has come across new challenges. On the one hand, the fertiliser industry has been asked to supply sufficient nutrients for plants to feed the growing population (Manning, 2015); on the other hand, they must tackle challenges, such as being more environmentally friendly, using cleaner energy systems and decarbonizing, thus facing increased regulatory pressure (Fertilizers Europe, 2018). While the first challenge can be expected to be in line with the self-interest of the industry, the second challenge is not necessarily so, as it often adds additional costs that are not necessarily met by additional benefits. In particular, FPR 2019/1009 of the EU addressing the second challenge takes effect on July 16, 2022, replacing the existing regulation, Fertilizer Regulation European Commission (EC) No. 2003/2003 (FR 2003/2003).

FPR 2019/1009 provides uniform standards under which fertiliser products can be traded among the EU. It follows the OHR, which means that the HR of the EU and IR of each country simultaneously exist. Companies not following FPR 2019/1009 could follow each country's standards and sell products in that country.

Compared with FR 2003/2003, FPR 2019/1009 addresses more environmental and material safety concerns (NUTRIMAN, 2019). All fertiliser products, including organic fertilisers, organ mineral fertilisers and bio stimulants, are covered by FPR 2019/1009, whereas FR 2003/2003 only applies to mineral fertilisers, and the others are regulated by EU member countries (European Community, 2003). Second, FPR 2019/1009 provides stricter and more comprehensive rules for safety and quality. Third, it provides specific requirements for processing, labelling and packaging, among others. Fourth, it introduces some new limits in fertilisers components to be more environmentally friendly, such as cadmium in phosphate fertilisers, from 60 mg/kg to 40 mg/kg after 3 years and to 20 mg/kg after 12 years (European Commission, 2016), which is considered a starting point for cadmium control in arable soils (Marini et al., 2020).

One aim of the OHR in FPR 2019/1009 is to improve the circulation of all fertilisers, which is not inconsistent with EU mutual recognition principles. According to mutual recognition principles, any goods sold lawfully in one EU country can be sold in another (European Union, 2019a). However, mutual recognition is often recommended as an ideal solution for removing obstacles to free trade (Kerber and Van den Bergh, 2008). With considerable practical problems, the sale and circulation of fertilisers within the EU are more constrained due to diverging national rules and standards (European Commission, 2016; Flausch, 2018), and developing cross-border markets for organic fertilising products has been proven to be difficult (European Commission, 2016). In such a situation, fertiliser suppliers must apply for approval from member countries if they want to sell products locally.

Through a comparison of these regulatory regimes, the contribution of this paper is the assessment of the impacts of regulatory heterogeneity on the new investments of transregional corporations of different sizes. Moreover, we build a real option model extending Purnhagen and Wesseler's (2019) approach to a multi-region situation regarding ex ante regulation and ex post liability. We conclude that under OHR, there is a threshold number of regions firms can follow HR, and firms running a business below the threshold are better off following IR. The threshold will decrease when considering an option of future possible expansion to more regions. We compare the shift in benefits of new investments from one regulatory regime to another and conclude that the impacts of regulatory heterogeneity vary with the sizes of transregional corporations. At last, we perform a Monte Carlo simulation regarding the EU fertilizer regulation which follows OHR to calculate the threshold's number of regions.

The rest of the paper is organised as follows. In Section 2, we present an overview of related literature. In Section 3, we introduce the real option model to assess the economic implications of transregional investment. In Section 4, we calculate the marginal effects and perform a Monte Carlo simulation based on the EU fertilizer markets to verify and validate our model. In Section 5, we provide the discussion points and conclusions.

2 Overview of the Literature

A variety of studies are conducted from various angles, discussing whether uniform regulation is beneficial or not. Many researchers have analysed harmonisation regimes from the perspectives of law and economics (Bergh and Visscher, 2006; Gomez, 2008; Kerber and Grundmann, 2006; Low, 2010). These studies have built a wide range of models and come up with different conclusions.

Numerous studies have shown that regulatory uniformity or harmonisation is an essential way for the free movement of products and a vital factor affecting new investments. Kox & Lejour (2005) discuss that many regulatory measures affect fixed market-entry costs, which are sunken investments, and that exports are negatively affected by regulatory heterogeneity. Winchester et al. (2012) compute a heterogeneity index of trade regulations and concluded that harmonising regulations would increase trade. Sykes (2000) proposes that regulatory competition through trade law, technical standardisation and tariff barriers can affect multinational corporations' profits and the economic performance of a country. Van Zwanenberg et al. (2008) find that the international harmonisation of regulations helps facilitate technology diffusion, trade and economic governance.

Other researchers have supported the idea that harmonising regulation is not the best solution. Kolstad (1987) addresses the situation where externalities, such as bad emissions, are regulated as if they are the same, showed that uniform regulation is less efficient than differentiated regulation, and concluded the efficiency loss under uniformity. Jackson (2002) finds that countries pursuing mixed strategies receive more benefits than those with harmonised policies. Gomez and Ganuza (2011) present a law and economic analysis of the harmonisation dimension between minimum and maximum harmonisation and concluded that the optimal solution could be superior to minimum or maximum harmonisation. Purnhagen & Wesseler (2019) and Wesseler et al. (2022) develop real option models to cope with uncertainties in harmonized regulation about new plant-breeding technologies and genetically modified microorganisms and thought that both minimum harmonisation and maximum harmonisation may not provide access to the entire EU market, but minimum harmonisation is expected to reduce research and approval costs and could provide stronger incentives than those based on maximum harmonisation.

To discuss regulation regimes, we implement a real option approach. Real options analysis uses option value techniques from finance about capital investment (Trigeorgis, 1996). The real option model is started by Arrow and Fisher (1974) and Henry (1974), and extended by researchers in many directions (Conrad, 1980; Dixit and Pindyck, 1994; Mezey and Conrad, 2010; Wesseler and Zhao, 2019). Dixit and Pindyck (1994) propose that irreversibility and uncertainty are crucial factors in evaluating whether a real options approach to valuation is necessary, especially in the field of natural resources. Mezey & Conrad (2010) describe the use of practical choices for the management and development of natural resources. Wesseler & Zhao (2019) review real options by examining what is known about the advantages of waiting—the good, the costs of waiting—the bad, and how strategic conduct might affect policies—the ugly.

When evaluating regulation harmonization, ex ante regulation and ex post liability are two popular means. Ex ante regulation regulates an activity before an accident, such as security standards and Pigouvian taxes, occurs. Ex post liability controls externalities only after harmful results have occurred, such as the threat of fines or suits. By comparing ex-post liability and ex-ante regulation, Kolstad et al. (1990) conclude that ex-post liability would lead to inefficiencies that could be corrected by ex-ante regulation. Shavell (1984) discuss different determinants affecting liability and regulation and concluded that some combination of both would be a good solution. Schwartzstein & Shleifer (2013) propose an activity-generating theory of regulation and concluded that whether regulation should pre-empt tort lawsuits depends on various market conditions.

In contrast to other scholars' research about regulatory harmonization, in this paper, we evaluate the regulation heterogeneity of multiple regions from the perspective of approval costs and procedures. Regarding ex ante regulation and ex post liability, we conclude that the increase of regulatory integration has different impacts on transregional corporations of different sizes. More specifically, we first conclude that under OHR, each firm can operate a threshold number of regions to follow HR, and firms running a business below the threshold are better off choosing to follow the IR of each region. The threshold will become smaller when taking into account a future option of expanding to other regions. We also find that the increase of regulatory integration will have a positive, or at least not negative, economic impact on firms bigger than the threshold, but will have a negative, or at least not positive, economic impact on firms smaller than the threshold.

3 Model

In this study, we consider a risk-neutral transregional corporation investing in new products in regions with different regulatory regimes. To compare the regulatory regimes of HR, IR and OHR, we build a real option model by extending the model of Purnhagen & Wesseler (2019) to a multi-regional situation regarding ex ante regulation and ex post liability and analyse the benefit shift through these regimes. When considering investing in a new product, the objective of a firm is to maximise its real option value. Under OHR, that is, firms will maximise their real option of choosing between HR and IR.

Based on Purnhagen & Wesseler (2019), the entire investment process includes three continuous phases: 1) a research phase, when the firm will invest a one-time research cost R and annual constant research cost r; 2) an approval phase, when the firm will invest a one-time approval cost A and annual constant research cost a; 3) a benefit phase, when the firm will get benefit B, expressed in net-present-value terms B_0 at the beginning of the stage and ex-post tort liability and/or reputation costs, θ, if any damages occur. The time length of each phase is denoted by random variables $\kappa_i \in (0, \infty)$, following an exponential failure function with $g(\kappa_i) = h_i e^{-h_i \kappa_i}$ and $E(\kappa_i) = \frac{1}{h_i}$ where h_i denotes the failure rate. Table 1 gives a specific explanation of each variable.

Table 1 Description of the variables in the model

Variable's category	Label	Description
Research phase	κ_1	The time length of the research phase
	h_1	The reciprocal of the expectation of κ_1
	R	One-time research cost
	r	Annual research cost
Approval phase	κ_2	The time length of the approval phase
	h_2	The reciprocal of the expectation of κ_2
	A	One-time approval cost
	a	Annual approval cost
Benefit phase	κ_3	The time length of the benefit phase
	h_3	The reciprocal of the expectation of κ_3
	B	Benefit
	B_0	Net-present-value terms of benefit
	θ	Ex-post tort liability and/or reputation costs

Other variables	μ	The discount rate
	$E(V)$	The expected value

Figure 1 demonstrates the three stages of the entire investment process. Note that each phase of the process finalises in an uncertain but finite amount of time.

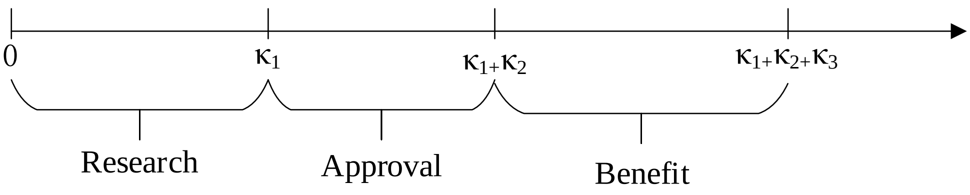

Figure 1 Overview of the three phases of the entire investment

Note that, for one region with one regulatory regime, the firm invests in products and applies for the region's approval. The expected value of the investment can be written as follows:

$$E(V_0) = -R + \int_0^{\infty}\left(\int_0^{\infty}\left(\int_0^{\infty}\left[-\int_0^{\kappa_1} r_t e^{-\mu t}\,dt - Ae^{-\mu\kappa_1} - \int_{\kappa_1}^{\kappa_1+\kappa_2} a_t e^{-\mu t}dt\right.\right.\right.$$

$$\left.\left.\left. + mB_0 e^{-\mu(\kappa_1+\kappa_2)} - m\theta e^{-\mu(\kappa_1+\kappa_2+\kappa_3)}\right] g(\kappa_1)d\kappa_1\right) g(\kappa_2)d\kappa_2\right) g(\kappa_3)d\kappa_3$$

Assuming r_t and a_t are constant, we could get (see Appendix A):

$$\mathrm{E}(V_0) = -\mathrm{R} - \frac{r + Ah_1}{\mu + h_1} - \frac{ah_1}{(\mu + h_1)(\mu + h_2)} + \frac{B_0 h_1 h_2}{(\mu + h_1)(\mu + h_2)} - \frac{\theta h_1 h_2 h_3}{(\mu + h_1)(\mu + h_2)(\mu + h_3)} \quad (1)$$

3.1 Benefit of HR and IR

Now, we assume a multi-region case, including n $(n > 1)$ regions with regulatory heterogeneity under OHR. For OHR, both HR and IR exist. A firm is considering investing in a product and forecast to sell the product in m $(1 \le m \le n)$ regions, and can choose HR or IR to obtain more benefits, so the objective of the firm is as follows:

$$\max\{\mathrm{E}_{(HR,m)}(V_0), \mathrm{E}_{(IR,m)}(V_0)\}$$

For HR, the firms undergo one research phase, one approval phase and m benefit phases from m regions. We assume that the benefits are identical for all regions. The variables in Table 2 are denoted in one region. We use the single apostrophe to denote variables under HR of multi-regions.

The expectation of HR with m regions is as follows:

$$
\begin{aligned}
\mathrm{E}_{(HR,m)}(V_0) = -R' \\
&+ \int_0^{\infty}\left(\int_0^{\infty}\left(\int_0^{\infty}\left[-\int_0^{\kappa'_1} r' e^{-\mu t}\,dt - A' e^{-\mu\kappa'_1} - \int_{\kappa'_1}^{\kappa'_1+\kappa'_2} a' e^{-\mu t} dt\right.\right.\right. \\
&+ m B'_0 e^{-\mu(\kappa'_1+\kappa'_2)} \\
&\left.\left.\left.- m\theta' e^{-\mu(\kappa'_1+\kappa'_2+\kappa'_3)}\right] g(\kappa'_1) d\kappa'_1\right) g(\kappa'_2) d\kappa'_2\right) g(\kappa'_3) d\kappa'_3
\end{aligned}
$$

We have (see calculations in Appendix B):

$$
\mathrm{E}_{(HR,m)}(V_0) = -\left(R' + \frac{r'}{\mu + h'_1}\right) - \frac{h'_1}{\mu + h'_1}\left(A' + \frac{a'}{\mu + h'_2}\right) + \frac{m h'_1 h'_2}{(\mu + h'_1)(\mu + h'_2)}\left(B'_0 - \frac{\theta' h'_3}{\mu + h'_3}\right) \quad (2)
$$

For IR, we simplify the problem that to get the highest profit, the firms' optimal choice is to do similar research with the largest research cost to satisfy all IR, and firms will start to apply for the approval of all regions after research. They will get benefits from all m regions after getting approval. Firms will undergo one research phase, m approval phases, and m benefit phases from m regions. The double apostrophe is used to denote variables under IR. For ease of analysis, we assume that for any region, A'', a'', h''_2, B''_0, θ'', and h''_3 are equal to those of other regions.

So, the expected value in IR with m regions is

$$\mathrm{E}_{(IR,m)}(V_0) = -R'' + \int_0^{\infty}\left(\int_0^{\infty}\left(\int_0^{\infty}\left[-\int_0^{\kappa''_1} r''e^{-\mu t}\,dt - mA''e^{-\mu\kappa''_1} - m\int_{\kappa''_1}^{\kappa''_1+\kappa''_2} a''e^{-\mu t}dt + mB''_0 e^{-\mu(\kappa''_1+\kappa''_2)} - m\theta''e^{-\mu(\kappa''_1+\kappa''_2+\kappa''_3)}\right] g(\kappa''_1)d\kappa''_1\right) g(\kappa''_2)d\kappa''_2\right) g(\kappa''_3)d\kappa''_3$$

We have:

$$\mathrm{E}_{(IR,m)}(V_0) = -\left(R'' + \frac{r''}{\mu + h''_1}\right) - \frac{mh''_1}{\mu + h''_1}\left(A'' + \frac{a''}{\mu + h''_2}\right) + \frac{mh''_1 h''_2}{(\mu + h''_1)(\mu + h''_2)}\left(B''_0 - \frac{\theta'' h''_3}{\mu + h''_3}\right) \quad (3)$$

3.2 Optimal strategies for OHR

In this situation, there is a prerequisite of OHR, that is under OHR, some firms choose HR and some choose IR. If the prerequisite does not exist, OHR will have no difference from HR or IR. So we have assumptions 1 and 2.

Assumption 1

For each region, $\mathrm{E}_{(IR,1)}(V_0) > \mathrm{E}_{(HR,1)}(V_0)$.

The reasons lie in the less strict standards and easier approval procedures for the regulation in each region compared with HR. For example, approximately 230 standards need to be created or updated to implement FPR 2019/1009 (Stephani, 2019). All of these will require higher investment and lead to a lower net present value. No firm will apply for IR if $\mathrm{E}_{(IR,1)}(V_0) < \mathrm{E}_{(HR,1)}(V_0)$. This is also a precondition for the OHR. If Assumption 1 fails, no firm will choose IR, which will then have no difference from HR under any conditions. Consequently, all the discussions below are in regions with $\mathrm{E}_{(IR,1)}(V_0) > \mathrm{E}_{(HR,1)}(V_0)$.

Starting with the simplest condition, a firm's product is sold in only one region. The firm's objective function is:

$$\max\{\mathrm{E}_{(HR,1)}(V_0), \mathrm{E}_{(IR,1)}(V_0)\}$$

Proposition 1

If a firm's products are to be sold in only one market, the optimal choice under OHR is to follow IR.

Proof

By Assumption 1, we know that for each region $\mathrm{E}_{(IR,1)}(V_0) > \mathrm{E}_{(HR,1)}(V_0)$; hence, the firm's objective for profit maximisation is as follows:

$$\max\{\mathrm{E}_{(HR,1)}(V_0), \mathrm{E}_{(IR,1)}(V_0)\} = \mathrm{E}_{(IR,1)}(V_0)$$

The optimisation leads to IR. □

Assumption 2

For all regions, $\mathrm{E}_{(IR,n)}(V_0) < \mathrm{E}_{(HR,n)}(V_0)$.

If Assumption 2 fails, the firm will choose IR no matter which regions it sells products and no firm choose HR, so OHR will have no difference with IR.

Now, suppose the firm invests in m markets, its objective will be:

$$\max\{\mathrm{E}_{(HR,m)}(V_0), \mathrm{E}_{(IR,m)}(V_0)\}$$

Proposition 2

With OHR, there is a threshold of region quantities for firms to invest in new products with HR.

Proof

If $\mathrm{E}_{(HR,m)}(V_0) > \mathrm{E}_{(IR,m)}(V_0)$, then with basic calculation, we reach a threshold value m_0* with $m > m_0*$. (See Appendix C)

$$m_0 * = \frac{\left(\mathrm{R}' + \frac{r'}{\mu + h'_1}\right) - \left(\mathrm{R}'' + \frac{r''}{\mu + h''_1}\right) + \frac{h'_1}{\mu + h'_1}\left(A' + \frac{a'}{\mu + h'_2}\right)}{\frac{h'_1 h'_2 (B'_0(\mu + h'_3) - \theta' h'_3)}{(\mu + h'_1)(\mu + h'_2)(\mu + h'_3)} + \frac{h''_1\left(A''\left(\mu + h''_2\right) + a''\right)}{(\mu + h''_1)\left(\mu + h''_2\right)} - \frac{h''_1 h''_2 (B''_0(\mu + h''_3) - \theta'' h''_3)}{(\mu + h''_1)(\mu + h''_2)(\mu + h''_3)}} \quad (4)$$

A positive number m_0* bigger than 1 exists; when $m < m_0*$, $\mathrm{E}_{(HR,m)}(V_0) < \mathrm{E}_{(IR,m)}(V_0)$, and firms will invest in new products with IR; when $m > m_0*$, $\mathrm{E}_{(HR,m)}(V_0) > \mathrm{E}_{(IR,m)}(V_0)$, and firms will invest in new products with HR. □

Figure 2 provides a more illustrative explanation of the changes in $\mathrm{E}(V_0)$ with market region quantity m of a firm for both HR and IR. At m_0*, the expectations of HR and IR are equal. The optimal choices for different m are indicated by solid lines. Hereafter, the threshold for the region quantity is m_0*. The optimal choice for a firm with $m > m_0*$ (Bigger firm, with bigger indicating greater than the threshold) follows HR; the optimal choice for a firm with $m < m_0*$ (Smaller firm, with smaller indicating smaller than the threshold) follows IR.

With assumptions 1 and 2, we have $\mathrm{E}_{(IR,1)}(V_0) > \mathrm{E}_{(HR,1)}(V_0)$ and $\mathrm{E}_{(IR,n)}(V_0) >$ $<_{(HR,n)}$ (V_0). So, we could get that the slope of HR is greater than IR, and the vertical intercept of HR is smaller (see proof in Appendix D).

$$\frac{h'_1 h'_2}{(\mu + h'_1)(\mu + h'_2)}\left(B'_0 - \frac{\theta' h'_3}{\mu + h'_3}\right) > -\frac{h''_1}{\mu + h''_1}\left(A'' + \frac{a''}{\mu + h''_2}\right) + \frac{h''_1 h''_2}{(\mu + h''_1)(\mu + h''_2)}\left(B''_0 - \frac{\theta'' h''_3}{\mu + h''_3}\right) \quad (5)$$

$$-\mathrm{R}'' - \frac{r''}{\mu + h''_1} > -\mathrm{R}' - \frac{r'}{\mu + h'_1} - \frac{h'_1}{\mu + h'_1}\left(A' + \frac{a'}{\mu + h'_2}\right) \quad (6)$$

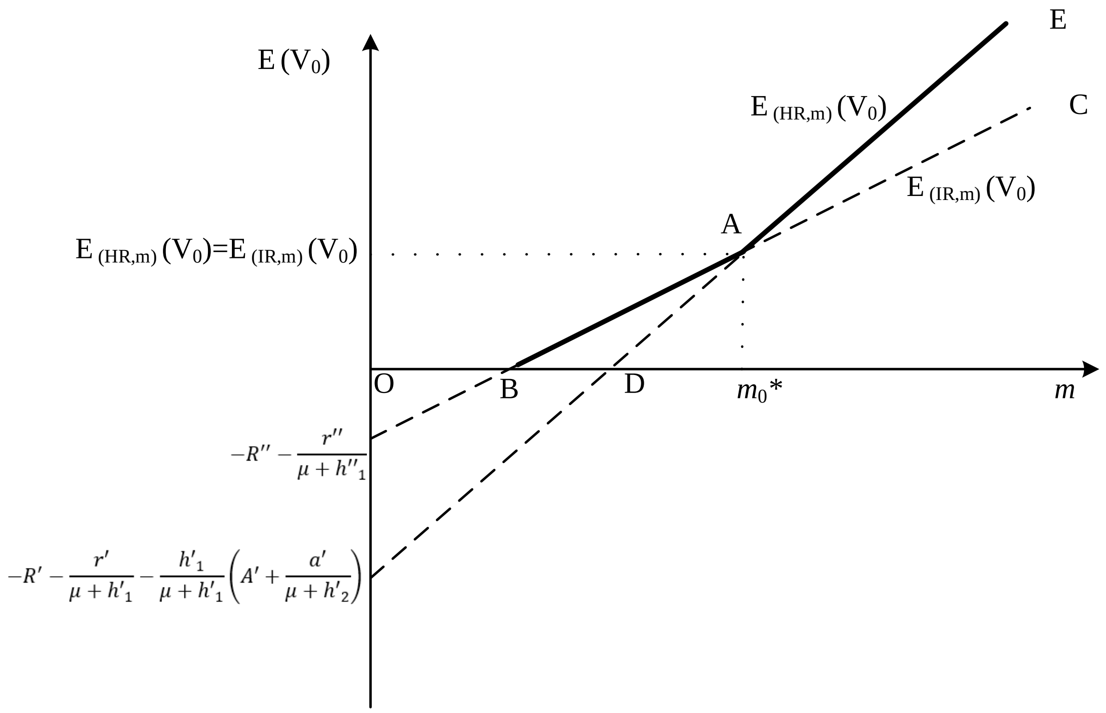

Figure 2 Changes of $\mathrm{E}(V_0)$ with the number of regions for both HR and IR

Proposition 3

Moving from IR to OHR, and then to HR, the increase of regulatory integration will have positive, or at least not negative, economic impacts on bigger firms but will have negative, or at least not positive, economic impacts on smaller firms. The decrease in regulatory integration will have the opposite influence.

Proof

From IR to OHR and then to HR, the degree of regulatory integration is increasing. Under IR, both bigger and smaller firms follow IR, and the expected value is shown as line BC in Figure 2. If the degree of regulatory integration increases from IR to OHR, smaller firms' optimal strategy will not change, but bigger firms' optimal choice will become HR, and the benefits will increase from AC to AE. If the degree of regulatory regimes increases from OHR to HR, bigger firms will still follow HR, but smaller firms must change from IR to HR. Then, the benefits will decrease from BA to DA, and even some very smaller firms' benefits may become negative with $\mathrm{E}(V_0) < 0$. Hence, theoretically, a possibility exists that very small firms will not invest in new products under HR but will do so under OHR. Furthermore, we can see opposite trends if the degree of regulatory integration decreases. □

Table 3 provides more details about the results of the change in regulation from the second column to the first row. The former item in the bracket identifies the change in the degree of regulatory integration, and the latter item in the bracket indicates the change in benefits. '+' is used for increasing, '-' for decreasing and '0' for no change. For example, the (+,-) marked with * means from IR to HR, the regulatory integration increases, but for smaller firms, the benefits decrease. We do not see '(+,-)' or '(-,+)' for bigger firms or '(+,+)' or '(-,-)' for smaller firms, because if regulatory integration increases, bigger firms' benefits will not decrease, and smaller firms' benefits will not increase. If regulatory integration decreases, bigger firms' benefits will not increase and smaller firms' benefits will not decrease.

Table 2 Change of benefits with the change of regulatory integration.

		IR	OHR	HR
Bigger Firms	IR	(0,0)	(+,+)	(+,+)
	OHR	(-,-)	(0,0)	(+,0)
	HR	(-,-)	(-,0)	(0,0)
Smaller Firms	IR	(0,0)	(+,0)	(+,-)*
	OHR	(-,0)	(0,0)	(+,-)
	HR	(-,+)	(-,+)	(0,0)

3.3 The option to expand under OHR

A very critical advantage of HR is that once approved, the product could be circulated to other regions without more approval procedures and costs. Now consider the firm has the option to expand, such as to one region, in future at a time, such as $\kappa_2 + 1$, with possibility p $(0 < p < 1)$. For HR, the firm does not need to ask for more approval and can just sell the product there. So, the expected value will be:

$$\mathrm{E}_{(HR,m+1)}(V_e) = \mathrm{E}_{(HR,m)}(V_0) + p\int_0^\infty \left(\int_0^\infty \left(\int_0^\infty \left[B'_0 e^{-\mu(\kappa'_1+\kappa'_2+1)} - \theta' e^{-\mu(\kappa'_1+\kappa'_2+1+\kappa'_3)}\right] g(\kappa'_1)d\kappa'_1\right) g(\kappa'_2)d\kappa'_2\right) g(\kappa'_3)d\kappa'_3$$

And the expected value is:

$$\mathrm{E}_{(HR,m+1)}(V_e) = -\left(R' + \frac{r'}{\mu + h'_1}\right) - \frac{h'_1}{\mu + h'_1}\left(A' + \frac{a'}{\mu + h'_2}\right) + \frac{mh'_1 h'_2}{(\mu + h'_1)(\mu + h'_2)}\left(B'_0 - \frac{\theta' h'_3}{\mu + h'_3}\right) + \frac{pe^{-\mu} h'_1 h'_2}{(\mu + h'_1)(\mu + h'_2)}\left(B'_0 - \frac{\theta' h'_3}{\mu + h'_3}\right) \quad (7)$$

For IR, the firm should ask approval from that region. To distinguish the expanding approval time and previous approval time, as they are not independent, we use κ''_{2e} to indicate the expanding approval time for the region. So, the expected value will be:

$$\mathrm{E}_{(IR,m+1)}(V_e)$$

$$= \mathrm{E}_{(IR,m)}(V_0)$$

$$+ p\int_0^\infty \left(\int_0^\infty \left(\int_0^\infty \left(\int_0^\infty \left[-A'' e^{-\mu(\kappa''_1+\kappa''_2+1)} - \int_{\kappa''_1+\kappa''_2+1}^{\kappa''_1+\kappa''_2+1+\kappa''_{2e}} a'' e^{-\mu t} dt\right.\right.\right.\right.$$

$$+ B''_0 e^{-\mu(\kappa''_1+\kappa''_2+1+\kappa''_{2e})}$$

$$\left.\left.\left.\left. - \theta'' e^{-\mu(\kappa''_1+\kappa''_2+1+\kappa''_{2e}+\kappa''_3)}\right] g(\kappa''_1) d\kappa''_1\right) g(\kappa''_2) d\kappa''_2\right) g(\kappa''_3) d\kappa''_3\right) g(\kappa''_{2e}) d\kappa''_{2e}$$

And we have:

$$\mathrm{E}_{(IR,m+1)}(V_e) = -\left(R'' + \frac{r''}{\mu + h''_1}\right) - \frac{mh''_1}{\mu + h''_1}\left(A'' + \frac{a''}{\mu + h''_2}\right) + \frac{mh''_1 h''_2}{(\mu + h''_1)(\mu + h''_2)}\left(B''_0 - \frac{\theta'' h''_3}{\mu + h''_3}\right) - \frac{pe^{-\mu} h''_1 h''_2}{(\mu + h''_1)(\mu + h''_2)}\left(A'' + \frac{a''}{\mu + h''_2}\right) + \frac{pe^{-\mu} h''_1 h''^2_2}{(\mu + h''_1)(\mu + h''_2)^2}\left(B''_0 - \frac{\theta'' h''_3}{\mu + h''_3}\right) \quad (8)$$

Similarly, we could have $m_e *$, when $m > m_e *$, $\mathrm{E}_{(HR,m+1)}(V_e) > \mathrm{E}_{(IR,m+1)}(V_e)$, the firm will choose HR; when $m < m_e *$, $\mathrm{E}_{(HR,m+1)}(V_e) < \mathrm{E}_{(IR,m+1)}(V_e)$, the firm will choose IR.

Let $\mathrm{E}_{(HR,m+1)}(V_e) = \mathrm{E}_{(IR,m+1)}(V_e)$, we could get

$$m_e * = \frac{\left(R' + \frac{r'}{\mu + h'_1}\right) - \left(R'' + \frac{r''}{\mu + h''_1}\right) + \frac{h'_1}{\mu + h'_1}\left(A' + \frac{a'}{\mu + h'_2}\right) - \frac{pe^{-\mu} h'_1 h'_2}{(\mu + h'_1)(\mu + h'_2)}\left(B'_0 - \frac{\theta' h'_3}{\mu + h'_3}\right) - \frac{pe^{-\mu} h''_1 h''_2}{(\mu + h''_1)(\mu + h''_2)}\left(A'' + \frac{a''}{\mu + h''_2}\right) + \frac{pe^{-\mu} h''_1 h''^2_2}{(\mu + h''_1)(\mu + h''_2)^2}\left(B''_0 - \frac{\theta'' h''_3}{\mu + h''_3}\right)}{\frac{h'_1 h'_2 (B'_0(\mu + h'_3) - \theta' h'_3)}{(\mu + h'_1)(\mu + h'_2)(\mu + h'_3)} + \frac{h''_1\left(A''\left(\mu + h''_2\right) + a''\right)}{(\mu + h''_1)\left(\mu + h''_2\right)} - \frac{h''_1 h''_2 (B''_0(\mu + h''_3) - \theta'' h''_3)}{(\mu + h''_1)(\mu + h''_2)(\mu + h''_3)}} \quad (9)$$

Proposition 4

When considering the future option to expand, the threshold of region quantities will become smaller.

Proof

The denominators of $m_e *$ and $m_0 *$ are same. The difference between numerators of $m_e *$ and $m_0 *$ is:

$$-\frac{pe^{-\mu}h'_1h'_2}{(\mu+h'_1)(\mu+h'_2)}\left(B'_0-\frac{\theta' h'_3}{\mu+h'_3}\right)$$
$$-\frac{pe^{-\mu}h''_1h''_2}{(\mu+h''_1)(\mu+h''_2)}\left(A''+\frac{a''}{\mu+h''_2}\right)+\frac{pe^{-\mu}h''_1h''^2_2}{(\mu+h''_1)(\mu+h''_2)^2}\left(B''_0-\frac{\theta'' h''_3}{\mu+h''_3}\right) \qquad (10)$$

When the left and right sides of equation (5) are multiplied by the negative formula, $-\frac{pe^{-\mu}h'_2}{\mu+h''_2}$, we could easily find that formula (10) is smaller than 0. As the numerator of m_0* is bigger than that of m_e*, we have $m_e*< m_0*$. □

4 Scenario Simulation

4.1 EU fertiliser regulation

The EU fertiliser regulation, FR 2003/2003 and FPR 2019/1009 follow OHR. FR 2003/2003 only lay down rules on a part of the mineral fertilisers, while FPR 2019/1009 regulates all fertilisers, including organic fertilisers, organ mineral fertilisers and biostimulants. Because of data limitations, in the simulation, we do not focus on a specific fertilizer but collect data about fertilizer in general.

The fertilizer registration procedures of EU member states differ a lot. To be consistent with our model, we consider also the three phases, the research phase, the approval phase and the benefit phase. For the research phase, European Biostimulants Industry Council (EBIC) reports that it generally takes 2—5 years to bring new biostimulants to market (EBIC, 2013), so we let the research time length be 2—5 years. As biostimulants manufacturers reinvest 3%—10% of turnover into R&D (EBIC, 2013), we let one-time research costs be 2%—8% of the benefit, annual research be 1%—2% of the benefit.

In the approval phase, the flat fee per dossier is about €400 in Germany, €300-500 in Denmark, €1,500 in Belgium, €6,000 in France, and the total cost for registration ranges from €20,000 to > €50,000 in France and €30,000 to €50,000 in Italy (Traon et al., 2014). It takes about 3 to 6 months to grant or refuse the registration in Spain, while the typical assessment time in Italy is 12 to 18 months and is expected to take 1 year but 2 years are necessary for the majority in France (Traon et al., 2014). So we let the one-time approval cost be €300—6,000, the time length be 0.25—5 years, and the annual approval cost be €5,000 to 20,000.

In the benefit phase, the registration authorisation is valid for 10 years in Hungary (Traon et al., 2014), also it is possible to be prohibited when encountering disastrous environmental issues, so we let the benefit phase be 5—10 years.

The liability cost could be highly related to the firms' scale. An estimate of liability cost could be the manufacturer's insurance. For instance, premiums of Contractors Pollution Liability Insurance from Beacon Hill Associates could start from $1,000 (Beacon Hill Associates, 2021), while InsuranceTrack Services reports the manufacturing business insurance cost could be as low as $400 per year but on average around $1500 per year (InsuranceTrack Services, n.d.). We let the liability cost be €400—3000 per year, which times the benefit time length will be the total liability cost. The benefit can vary a lot regarding fertilizer products, geographic differences and company market shares. In this paper, we only simulate a small or medium company with the benefit being €50,000—100,000 in one region.

4.2 Monte Carlo simulation

We use a Monte Carlo method to simulate the fertilizer markets. For HR, the corresponding variables are the same as indicated above. For IR, we assume that compared with HR, the research and approval costs are smaller, research and approval time lengths are shorter, and the variables in the benefit phase are equal. All variables are evenly distributed. We perform the simulation by 100,000 times, select 50,933 samples with a profit margin between -50% to 50% regarding the reality, and get the means of all variables in Table 3 (see the codes in supplementary material).

Table 3 EU fertiliser regulation simulation for 50,993 times

Variable's category	**Label**	**Range**	**Mean (HR)**	**Mean (IR)**

Research phase	κ_1	2—5	3.49	3.20
	h_1	0.2—0.5	0.29	0.31
	R	$(2—8\%) * B_0$	3351	3127
	r	$(1—2\%) * B_0$	1334	1538
Approval phase	κ_2	0.25—5 years	2.18	0.84
	h_2	0.2—4	0.46	1.19
	A	€300—6,000	3112	1241
	a	€5,000—20,000	11593	6643
Benefit phase	κ_3	5—10 years	6.74	6.74
	h_3	0.1—0.2	0.15	0.15
	B_0	€50,000-100,000	80561	80561
	θ	$(€400—3000) * \kappa_3$	7919	7919
Other variables	μ		0.04	
	p		0.5	

Now we fix all variables at the means in Table 3, we could get the expected values for HR and IR as

$$\mathrm{E}_{(HR,m)}(V_0) = -30509.32 + 60000.18\mathrm{m}$$

$$\mathrm{E}_{(IR,m)}(V_0) = -7732.404 + 57843.83\mathrm{m}$$

And we could get the threshold $m_0 *= 10.56$. That is, a firm running the business in ten or fewer regions will apply for IR, while a firm selling fertiliser in 11 or more regions will apply for HR.

If the firm considers the option to expand to one region in future at a time $\kappa_2 + 1$ with possibility $p = 0.5$, the expected value of HR and IR will be

$$E_{(HR,m+1)}(V_e) = -1685.545 + 60000.18m$$

$$E_{(IR,m+1)}(V_e) = 19149.22 + 57843.83m$$

And we could get the threshold $m_e *= 9.66$. That is when considering a future option to expand to one region, the firm running the business in nine or fewer regions will apply for IR, and selling products in ten or more regions will apply for HR. Figure 3 and 4 demonstrates more illustrative explanations. With the region quantity increase, both expected values of HR and IR go up. The abscissa of the intersection point of considering expansion (Figure 4) is smaller than not considering expansion (Figure 3).

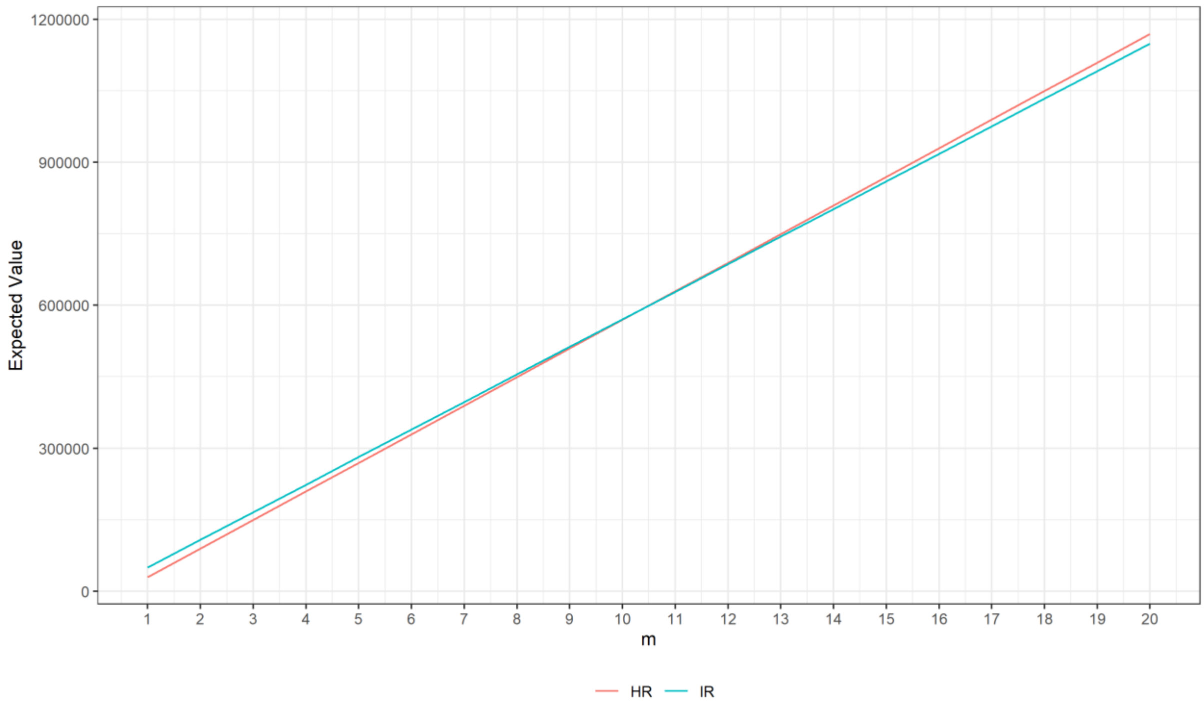

Figure 3 The expected value for HR and IR with simulation data without considering expanding.

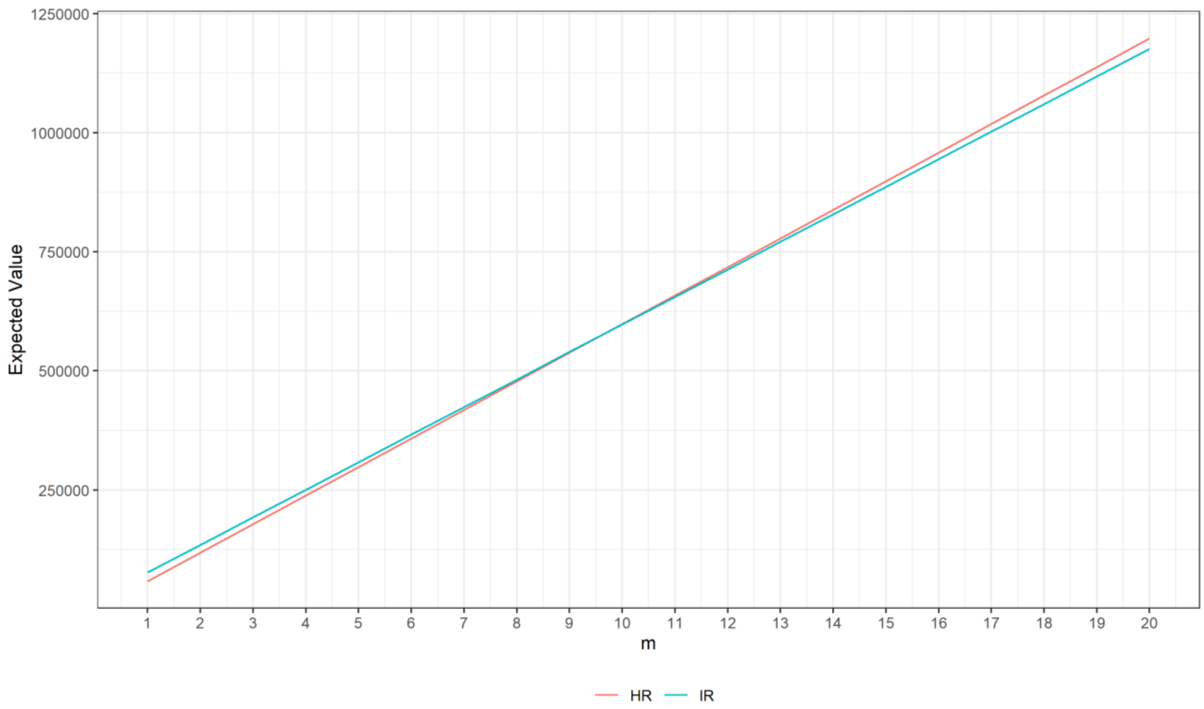

Figure 4 The expected value for HR and IR with simulation data when considering expanding.

5 Discussion and Conclusion

Regulatory heterogeneity has considerable effects on firms' investments. We compare three regulatory regimes—HR, IR and OHR—and find that there is a threshold number of regions each firm can operate to follow HR, and firms running a business below the threshold are better off choosing to follow IR. When the regulatory integration increases from IR to OHR and then to HR, it will have a positive, or at least not negative, economic impact on firms bigger than the threshold but will have a negative, or at least not positive, economic impact on firms smaller than the threshold. The decrease in regulatory integration will have the opposite influence.

This economic model can be extended and applied to simulate different scenarios by adjusting parameters in specific fields. For example, companies spend 556 days registering a new cereal variety in the Netherlands, but only 993 days in Norway (World Bank Group, 2019). In Nigeria, manufacturers spend 367 days registering a new cereal variety, but only 14 days registering a tractor. In Bangladesh, firms take 945 days and USD 699.23 to register a fertiliser (World Bank Group, 2019). Following different parameters, companies can choose how to optimise harmonisation strategies or whether to invest in a new product.

However, this study has several limitations. The assumption that all regions have equal parameters is a strong assumption. When considering the diversity of the regions' parameters with such different approval costs and benefits, it becomes more complicated. For instance, in 2018, 10.2 million tonnes of nitrogen fertiliser were consumed in the EU. The largest consumer, France, used 2.1 million tonnes; the second-largest consumer, Germany, consumed 1.5 million tonnes. Malta consumed only 0.6 million tonnes[1]. The market sizes of different countries vary significantly. The consumption of different fertiliser varieties, such as nitrogen and phosphorus, differs considerably among EU members. Furthermore, suppliers have different market shares than their competitors in different countries. All of these factors lead to different predicted benefits before investment. Firms usually have an outlook and a forecast on how many new products could be sold, and on approval and liability costs.

Another limitation is that this model considers only economic benefits. Regulations of maximum, minimum or optional harmonisation not only affect firms' benefits and investment behaviours but also have a great influence on total social welfare. In addition to economic benefits, environmental impact is also a vital factor in evaluating policies. In general, higher-level regulations always yield higher criteria. As introduced in the introduction section, FPR 2019/1009 will expand the scope of bio-based fertilisers and provide new limit values for contaminants in fertilisers, which is more environmentally friendly than FR 2003/2003.

The harmonisation of different levels may engender more possibilities. By making the model more general, we can find more levels of harmonisation. In the model above, we assumed a two-level harmonisation: 1) non-harmonisation (i.e., suppliers should only meet countries' standards and apply for countries' approval); 2) within-organisations'

[1] From Eurostat https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_mineral_fertiliser_consumption

harmonisation, such as the EU (i.e., companies could either apply for countries' approval or EU approval). Now, assuming a three-level harmonisation, besides the two mentioned, we would have a 3) wider international organisations' harmonisation, like the International Organization for Standardization (ISO). The ISO is the most widely recognised standard-setting body in the world, and its standards are commonly incorporated into domestic law and international agreements (Koppell, 2011). Firms could choose to follow national standards, EU standards or ISO standards. How to maximise profits will be more complex.

References

Arrow, K. J., and Fisher, A. C. (1974). Environmental Preservation, Uncertainty, and Irreversibility*. *The Quarterly Journal of Economics 88*: 312–319.

Beacon Hill Associates. (2021, October 18). *Environmental Insurance for Fertilizer Applicators*. https://b-h-a.com/blog/environmental-insurance-for-fertilizer-applicators/ , last accessed 17 February 2023.

Bergh, R. V. den, and Visscher, L. (2006). The Principles of European Tort Law: The Right Path to Harmonization? *European Review of Private Law 14*: 511–542. Q2.

Conrad, J. M. (1980). Quasi-Option Value and the Expected Value of Information. *The Quarterly Journal of Economics 94*: 813–820.

Dixit, R. K., and Pindyck, R. S. (1994). *Investment under Uncertainty*. Princeton University Press.

EBIC. (2013). *Economic Overview of the European Biostimulants Market*. https://biostimulants.eu/highlights/economic-overview-of-the-european-biostimulants-market/ , last accessed 17 February 2023.

European Commission. (2016). *Circular economy: New Regulation to boost the use of organic and waste-based fertilisers*.

https://ec.europa.eu/commission/presscorner/detail/en/IP_16_827 , last accessed 22 December 2021.

European Community. (2003). *Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers*.

European Union. (2019a). *Regulation (EU) 2019/515 of the European Parliament and of the Council of 19 March 2019 on the mutual recognition of goods lawfully marketed in another Member State and repealing Regulation (EC) No 764/2008*.

European Union. (2019b). *Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003*.

Fertilizers Europe. (2018). *Feeding life 2030: the European Fertilizer Industry at the Crossroads between Nutrition and Energy*. Fertilizers Europe.

Flausch, M. (2018). *The EU finally provides legal framework for organic and recycled fertilisers*. https://www.euractiv.com/section/agriculture-food/news/the-eu-finally-provides-legal-framework-for-organic-and-recycled-fertilisers/ , last accessed 22 December 2021.

Gomez, F. (2008). The Harmonization of Contract Law through European Rules: a Law and Economics Perspective. *European Review of Contract Law 4*: 1–30.

Gomez, F., and Ganuza, J. J. (2011). An Economic Analysis of Harmonization Regimes: Full Harmonization, Minimum Harmonization or Optional Instrument? *European Review of Contract Law 7*: 275–294.

Henry, C. (1974). Investment Decisions Under Uncertainty: The ‘Irreversibility Effect’. *The American Economic Review 64*: 1006–1012.

InsuranceTrack Services. (n.d.). *Manufacturing Business Insurance Cost*. https://www.insurancetrak.com/insurance-by-industry/manufacturers-insurance , last accessed 17 February 2023.

Jackson, L. A. (2002). *Is Regulatory Harmonization Efficient? The Case of Agricultural Biotechnology Labelling*. University of Adelaide, Centre for International Economic Studies.

Kerber, W., and Grundmann, S. (2006). An optional European contract law code: Advantages and disadvantages. *European Journal of Law and Economics 21*: 215–236. Q3/Q4.

Kerber, W., and Van den Bergh, R. (2008). Mutual Recognition Revisited: Misunderstandings, Inconsistencies, and a Suggested Reinterpretation. *Kyklos 61*: 447–465. Q3.

Klaus, B., and Meier, V. (2020). *Changes to harmonize EU fertilizer legislation: The new Regulation (EU) No. 2019/1009*. https://www.roedl.com/insights/life-sciences-law/eu-regulation-20191009-fertiliser-legislation-manufacturer-traceability-enterprise , last accessed 22 December 2021.

Kolstad, C. D. (1987). Uniformity versus differentiation in regulating externalities. *Journal of Environmental Economics and Management 14*: 386–399. Q1/Q2.

Kolstad, C. D., Ulen, T. S., and Johnson, G. V. (1990). Ex Post Liability for Harm vs. Ex Ante Safety Regulation: Substitutes or Complements? *American Economic Review 80*: 888–901. Q1.

Koppell, J. (2011). International organization for standardization. *Handb Transnatl Gov Inst Innov 41*: 289.

Kox, H., and Lejour, A. M. (2005). *Regulatory heterogeneity as obstacle for international services trade* , Vol. 49. CPB Netherlands Bureau for Economic Policy Analysis The Hague, the Netherlands.

Low, G. (2010). The (ir)relevance of harmonization and legal diversity to European Contract Law - A perspective from Psychology. *European Review of Private Law 38*: 285–305. Q2.

Manning, D. A. C. (2015). How will minerals feed the world in 2050? *Proceedings of the Geologists' Association 126*: 14–17.

Marini, M., Caro, D., and Thomsen, M. (2020). The new fertilizer regulation: A starting point for cadmium control in European arable soils? *Science of The Total Environment 745*: 1–9.

Mezey, E. W., and Conrad, J. M. (2010). Real Options in Resource Economics. *Annual Review of Resource Economics 2*: 33–52. Q1.

NUTRIMAN. (2019). *The new fertiliser regulation – consequences for farmers*. https://nutriman.net/EU-Fertiliser-Regulation , last accessed 22 December 2021.

Purnhagen, K. P., and Wesseler, J. H. (2019). Maximum vs minimum harmonization: what to expect from the institutional and legal battles in the EU on gene editing technologies. *Pest Management Science 75*: 2310–2315. Q1.

Schwartzstein, J., and Shleifer, A. (2013). An Activity-Generating Theory of Regulation. *The Journal of Law and Economics 56*: 1–38.

Shavell, S. (1984). Liability for Harm versus Regulation of Safety. *The Journal of Legal Studies 13*: 357–374.

Stephani, T. (2019, August). EU Fertilizing Products Regulation: where next? *Fertilizer Focus* : 8–10.

Suttmeier, R. P., Yao, X., and Tan, A. Z. (2009). Standards of power? Technology, institutions, and politics in the development of China's national standards strategy. *Geopolitics, History, and International Relations 1*: 46–84.

Sykes, A. (2000). Regulatory competition or regulatory harmonization? A silly question? *Journal of International Economic Law 3*: 257–264. Q1.

Sykes, Alan. (1999). Regulatory Protectionism and the Law of International Trade. *The University of Chicago Law Review 66*: 1–46.

Traon, D., Amat, L., Zotz, F., and Jardin, P. (2014). *A Legal Framework for Plant Biostimulants and Agronomic Fertiliser Additives in the EU*.

Trigeorgis, L. (1996). *Real options: managerial flexibility and strategy in resource allocation*. Cambridge, Mass: MIT Press.

van Zwanenberg, P., Ely, A., and Smith, A. (2008). *Rethinking regulation: international harmonisation and local realities*. STEPS Centre.

Wesseler, J., Kleter, G., Meulenbroek, M., and Purnhagen, K. P. (2022). EU regulation of genetically modified microorganisms in light of new policy developments: Possible implications for EU bioeconomy investments. *Applied Economic Perspectives and Policy* : 1–21. Q1.

Wesseler, J., and von Braun, J. (2017). Measuring the Bioeconomy: Economics and Policies. *Annual Review of Resource Economics 9*: 275–298.

Wesseler, J., and Zhao, J. (2019). Real Options and Environmental Policies: The Good, the Bad, and the Ugly. *Annual Review of Resource Economics 11*: 43–58. Q1.

Winchester, N., Rau, M.-L., Goetz, C., Larue, B., Otsuki, T., Shutes, K., Wieck, C., Burnquist, H. L., Pinto de Souza, M. J., and Nunes de Faria, R. (2012). The Impact of Regulatory Heterogeneity on Agri-food Trade. *The World Economy 35*: 973–993.

Wiser, R., Namovicz, C., Gielecki, M., and Smith, R. (2007). The Experience with Renewable Portfolio Standards in the United States. *The Electricity Journal 20*: 8–20.

World Bank Group. (2019). *Enabling the Business of Agriculture 2019*. World Bank, Washington, DC.

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