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Price transmission analysis of Irish butter export prices in the world butter market

RESEARCH ARTICLE

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Abstract

In 2019, Ireland was the third-largest exporter of butter in the world butter market but Irish butter prices have been more volatile compared to other Irish dairy products. Yet, empirical research that examines the market price dynamics and international competitor behavior in the butter market remains scarce. The Vector Error Correction Model was applied to data from 1970–2019, to test the extent to which changes in competitor butter prices and Irish farm milk prices had an impact on Irish butter prices. The results provide evidence of asymmetric price transmissions, Irish butter prices were more responsive to shocks in New Zealand (NZ) butter prices and Irish farm milk prices in the long-run. Declining world milk prices over time, related to milk supply, perishability and storability factors, may prevent symmetric response of Irish milk prices to changes/shocks in Irish butter prices. Moreover, different target markets and EU/NZ policies for Ireland and NZ butter may prevent symmetric response of Irish butter prices to changes/shocks from NZ butter prices. Essentially, the take home message for the butter industry is that Irish butter prices must not be studied in isolation, NZ is a major butter competitor to Ireland in the world market and NZ butter prices play a significant role on how Irish butter prices change.

Keywords: horizontal and vertical price transmission, butter export prices, farm milk prices, Vector Error Correction Model
JEL codes: L1, L5, Q1

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1. Introduction

In 1973, Ireland joined the European Union (EU) and this helped to open new markets for Irish agricultural exports outside the United Kingdom (UK) market which was the main importer of Irish butter. During that time, the price received for Irish butter exports was low in the UK market due to competition from New Zealand (NZ) (Donnellan *et al*., 2015). The situation has changed significantly since that time. The top five destinations of Irish butter exports in 2019, in value terms, were Netherlands (27%), United States (US) (18%), UK (18%), Germany (11%), and Belgium (9%) (Bord Bia, 2020). In 2019, Ireland exported €1.1 billion worth of butter, making it the third-largest exporter of butter in the world after NZ (€2.2 billion) and the Netherlands (€1.4 billion) (OEC, 2019). The dairy exports sector (€4.4 billion) had the highest contribution to the total food and drinks exported (€12.2 billion) by Ireland in 2019 and butter exports were worth €961 million in 2020, the most valuable of all the dairy sub-categories, in value terms (Bord Bia, 2020). Figures 1 and 2 provide an illustration of the significance of the Irish butter in domestic and world markets. From 2000 to 2019, the growth rate was the highest for cheese, whey, and butter at 281%, 238%, and 209%, respectively, as shown in Figure 1. Within the same period, the net export value for butter increased by 268% and 216% for NZ and Ireland, respectively, as shown in Figure 2. A recent study by Cele *et al*. (2022) also found that Irish butter was the most competitive compared to other dairy products in the country and compared to other to countries producing butter.

According to Hockmann and Voneki (2006), the milk market is considered to be among the most protected agricultural markets in the world. Butter and skimmed milk powder are the main dairy products monitored for the EU's Common Agricultural Policy (CAP) to regulate the dairy market. The CAP rules for market management were put in place to limit distortion in international competition and to ensure the competitive price positioning of these products in the international market. The information on butter and skimmed milk powder production, price and the volumes traded including raw cows' milk was essential for the milk market stakeholders in the EU to be able to react effectively to the market signals and risks in the world food market

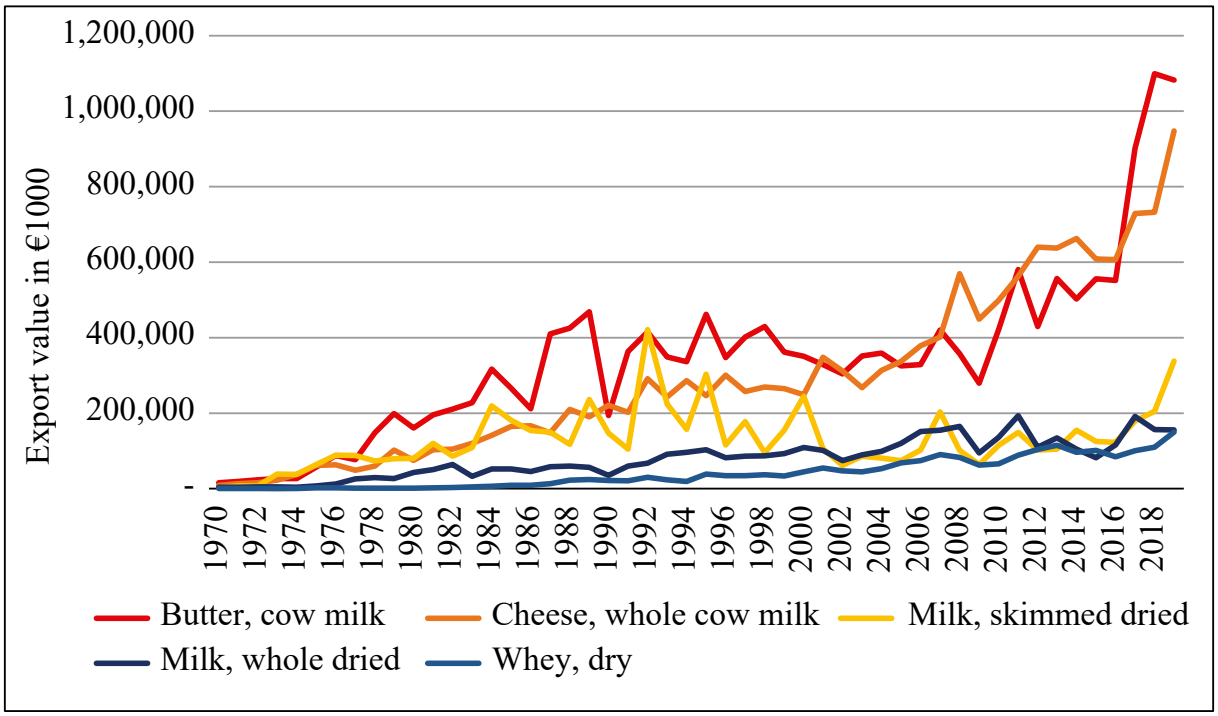


Figure 1. Export value for Irish dairy products. Source: Adapted from FAOSTAT.

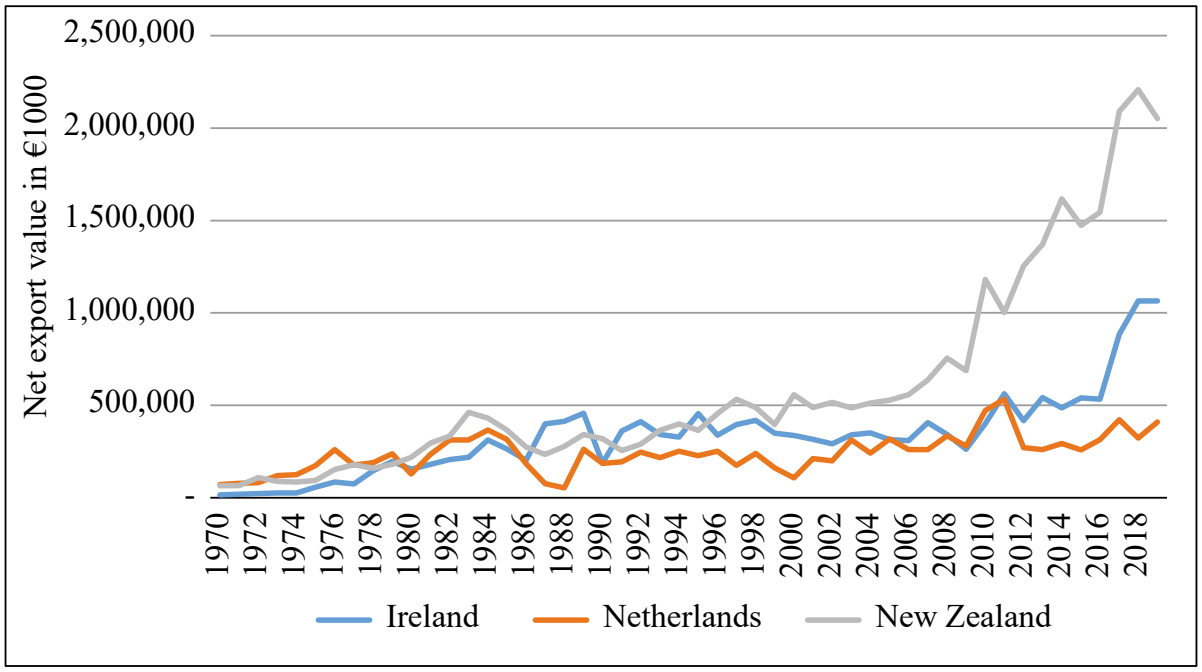


Figure 2. Net export value of butter from top 3 exporting countries in the world. Source: authors' estimates based on FAOSTAT dataset.

(Xue *et al*., 2018). Post-removal of CAP market interventions, policymakers have to rely on specialized past information for countries and dairy products to contribute to the discussions on the national policy measures in the long-term which will be provided in this study. According to Liu *et al*. (2019) and Ramsey *et al*. (2021), one major concern of the asymmetries in milk price transmission within the supply chain is that retailers can benefit from retail price lags in response to decreases in the farm price, but farmers might not reap those benefits. In Ireland, the production of butter absorbs the highest percentage of whole milk fat and protein content (Donnellan *et al*., 2015) which raises the question of price transmission between the prices of butter and milk. In some cases, the relationship between butter and milk prices has been discussed but has not been empirically tested in the literature (Chavas and Mehta, 2004; Xue *et al*., 2018), especially in the post milk quota period for Ireland.

The trade of dairy commodities has become an increasingly important component of international food trade due to the general drive for trade liberalization and innovations in milk processing (Fousekis and Trachanas, 2016; Zhang *et al*., 2017). For example, the volatility of the US market prices for butter and the significant growth in Irish butter imports in the US post-2014 led to an ad valorem tariff rate of 25% in 2015 instituted by the US (Newton, 2016). According to Xue *et al*. (2018), the butter price dynamics of different exporters can be linked to each other in the world market. Prices reflect equilibrating forces in a market setting and provide vital signals for the allocation of resources by economic agents. The pattern and strength of price linkages provide useful information on whether a given set of spatial markets are integrated (price shocks in one market evoke responses in other markets) or segmented (Liu *et al*., 2019; Serra and Goodwin, 2003). That information is useful for setting up new trade policy instruments and informing the need for public policy (McCorriston, 2015). Many factors can disrupt the supply of the butter industry and its prices, namely, policy changes such as tariffs and quotas, changes in the sustainable supply of raw materials, economic and environmental shocks, and international trade disputes which may result in a loss of revenue growth momentum (McCorriston, 2015; Ornua, 2019). Irish butter prices were the most volatile compared to other high-value dairy products in recent years (Ornua, 2019). Price competitiveness (proxy by export price) for

homogenous goods like butter is one the good indicators for tracking and understanding the market price dynamics and competitor behavior (Bakucs *et al*., 2014).

Price transmission refers to a process through which information is transmitted between participants in a market where measures involves comparative static or dynamic price relationships (Vercammen, 2011; Lloyd, 2017). The transfer of prices can occur horizontally (or spatially) which is concerned with how prices of the same good relate to one another at different regions or markets (influenced by a range of macroeconomic factors and government policy intervention), and vertically which focuses on the value chain from farm to trade, such as how the price of a processed product impacts on the farm-level raw material price (farmer behaviour) and vice versa (McCorriston, 2015). Price transmission can be symmetric or asymmetric in terms of differences in transmission speed and/or magnitude between markets. For example, if a price increase or decrease is completely and rapidly transmitted from one market to another, the transmission is symmetric; otherwise, it is asymmetric. In an integrated market system, price in the buying country should be equal to the price in the selling country (symmetric) (Vercammen, 2011; Lloyd, 2017). However, the convergence of prices in the long-run does not necessarily imply efficient allocation of resources unless the setting in which trade takes place is competitive (Baffes and Ajwad, 2001; Vercammen, 2011). Therefore, the assumption in this manuscript is that, the more symmetrical the prices, the more competitive the sector or country (rapid and complete price transmission as a proxy measure of competitiveness). The effective distribution of benefits among the food value chain is crucial to remain competitive and to ensure that various economic actors fully benefit from agricultural policy reforms toward greater market orientation (McCorriston, 2015).

There are several reasons why studying price transmission is important. Price transmission provides price transparency and risk management along the value chain and across markets (Baffes and Ajwad, 2001; McCorriston, 2015), especially when pricing issues are high on the list of concerns of stakeholders and policy-makers in the food chain. A high degree of pricing integration is a standard feature of competitive global commodity markets and a measure of relative price performance (Vercammen, 2011; Ramsey *et al*., 2021). Economists who study market competition, performance, efficiency, and integration, are interested in price transmission processes, i.e. for improved perception of domestic and foreign market developments or uncertainty, and better understanding and knowledge of foreign market conditions (Vercammen, 2011; Ramsey *et al*., 2021). Price transmission allows an industry to be brought directly into the analysis, rather than assuming away the price relationships that exists (McCorriston, 2015; Lloyd, 2017). Price transmission provides a yardstick with which to measure the functioning of markets, and a brief review of the micro and macro dimensions uncovers a unifying theme, namely the importance of competition in the value chain. The extent and dynamics of price adjustments are key indicators of the behaviour of participants in the value chain and its overall functioning (Baffes and Ajwad, 2001; Vavra and Goodwin, 2005; Von Cramon-Taubadel, 1998).

The paper contributes to knowledge on the world butter markets by documenting the complex nature of price dynamics and assessment of the degree of integration, more specifically for Ireland. By addressing the following questions: To what extent are changes in butter export price behavior transmitted to the farm milk price behavior in the value chain and vice versa? To what extent are spatial butter export prices for the Netherlands and New Zealand in the world market, integrated with Irish butter export prices and vice versa? These questions are addressed by taking into account the size of the shock causing changes in the long-run prices (magnitude), the significant lags of the adjustment (speed) and the extent to which adjustments are asymmetric. According to Fousekis and Trachanas (2016), depicting and analyzing the paths of adjustment and/or the duration of the disequilibrium following initial positive or negative disturbances in prices adds useful information about the long- and short-run patterns of asymmetry. The findings may assist butter industry stakeholders to draw lessons from butter price responses and influence trade expectations more precisely. The information on asymmetric price transmission allows processors to make some inferences about the behavior of different competitors in the market, particularly as their actions impact links across different market levels (Bakucs *et al*., 2014). The flexibility of the Irish butter market to absorb domestic- and foreign-origin shocks is of paramount importance. According to Vercammen (2011) and Ramsey *et al*.

(2021), a high degree of pricing integration is a standard feature of competitive global commodity markets and measure for relative price performance. Price transmission in this paper covers competition and price behaviour. Therefore, the study seeks to provide price transparency along the value chain. It addresses some concerns that may exist about farm milk prices and butter export prices, i.e. the idea that farmers may not see full benefits of higher export prices.

2. Literature review

In recent years, there has been an increase in the literature seeking to understand the price transmissions within the dairy industry which were mainly driven by globalization and policy changes. A recent study by Zhang *et al*. (2017) argued that EU dairy prices were more likely to be affected by international demand and supply developments than before, due to the abolition of the milk quota, reduction of export subsidies and the expansion of dairy production. According to Vercammen (2011), the storage capacity of stocks and production uncertainty are key determinants of price for many of the world's major agricultural commodities. In addition, according to Abeysinghe and Yeok (1998), export prices can be decomposed into four components, namely: (i) cost of raw materials and intermediate goods, which are domestically produced or imported, (ii) labor cost at the firm level for processed products, (iii) rentals and utilities, and (iv) profit mark-up. The pattern of price transmission in the dairy industry is often considered to be asymmetric because of the positive price shocks that are transmitted with higher intensity compared to negative price shocks (Olipra, 2020). Although a country may be unable to influence the global economic conditions that influence prices (price-taker), an analysis of the dynamics and factors that influence it may help to provide a certain level of understanding of a sector, especially for mitigating risks (Vercammen, 2011; Zhang *et al*., 2017). According to Xue *et al*. (2018), price fluctuations can hinder the viability of agricultural producers and processors through vertical price transmission whereby sudden price changes in inputs and commodities can flow through the chain. For example, Chavas and Mehta (2004) found evidence of asymmetric price transmissions in the US butter market between wholesale and retail prices and argued that price volatility varies with market conditions.

Previous studies that have analyzed price shocks and the long-run price relationships in the dairy industry have been from an international perspective (horizontal price dynamics) for different sectors within dairy. For example, Newton (2016) for all major dairy product markets, Hockmann and Voneki (2006), O'Connor *et al*. (2007) and Xue *et al*. (2018) for butter markets, Fousekis and Trachanas (2016) for skimmed milk powder markets and Zhang *et al*. (2017) for whole milk powder markets. Most studies have used the vector autoregressive (VAR) and vector error correction (VEC) models to examine price transmission effects in dairy markets or the relationship between national milk prices and dairy product prices in international milk markets. In the US, Newton (2016) argued that international dairy commodity prices influence the US commodity prices which then influence the US national milk price. A similar trend is tested for Ireland in this study, including the post-quota period, whereby New Zealand and Netherlands butter prices are expected to influence Irish butter prices which then will influence farm milk prices. Hockmann and Voneki (2006) found that international butter prices in the EU and Oceania are integrated and their response to shock corresponded with theoretical reasoning that higher prices on the world market for one region lead to higher prices in the second region. However, the regional analysis for butter often fails to capture the nuances that exist within the regions and assumes that countries within a region are homogenous and ignore the specialization of countries in different dairy products. For example, countries such as the Netherlands and Ireland may respond differently to policy and market changes because of the differences in their portfolio mix for dairy products and strategic objectives they have for different markets or products, even though they are both in the EU.

3. Data sources

The annual time series data for farm milk (1975–2019) and butter (1970–2019) prices were collected from Irish Central Statistics Office (CSO) and Food and Agriculture Organization Statistical Databases (FAOSTAT). The monthly time series data (January 2005–October 2021) for farm milk and butter was also collected from

CSO for vertical price transmission. The farmers are paid monthly for their milk and the annual time series for vertical price transmission was considered too short for reliable estimation (Bakucs *et al*., 2014). The length of the data sample was determined by the availability of the data. The study uses the latest price data, accounting for the pre and post milk quota period that led to structural changes which could have influenced the degree to which price shocks were regionally transmitted (Serra *et al*., 2006). There was no aggregation of data for different countries, which has been the case for previous studies. The selection of countries, i.e. Ireland, the Netherlands (proxy for EU — similar market conditions) and New Zealand (proxy for world — different market conditions), was motivated by their significance in the world trade of dairy products. The annual data was used for horizontal price transmission and was more appropriate to show the long-run price adjustments before, during and after the EU milk quota policy which was introduced in 1984 and officially abolished in 2015. Bergmann *et al*. (2016) found that a dummy variable for the abolishment of the EU milk quota was not statistically significant in their regression model. In our case, the dummy variable for the EU milk quota policy was not included in the VEC models due to collinearity issues it has with both the milk and butter prices, since they already account for its effects.

The prices were adjusted from USD to EURO based on historical exchange rates from FAOSTAT. Product selection was based on product homogeneity and trading volumes leading to volatile export unit values, which is important for price transmission modelling (Norwood and Lusk, 2008). Milk and butter are relatively homogenous goods which makes them useful for comparability. An important note to make is that for vertical price transmission, farm milk was a single major input to the production process that also includes labor and capital equipment but information on these other two inputs is scarce. Therefore, farm milk is considered to be a sufficient proxy of butter input for this study, especially since there is a lack of transparency or data available at the processing level. Consequently, the exact causes of imperfect price transmission in vertical markets are difficult to identify solely based on the model results, but the findings from existing data are still worth presenting and discussing (Ramsey *et al*., 2021).

4. Trends in butter and milk prices and production

Ireland is ranked among the top three exporters of butter in the world. Figures 3 and 4 illustrate the export butter prices and quantity exported, respectively, by NZ, the Netherlands and Ireland. The prices fluctuated around each other (converged) pre-1973 between Ireland and NZ, pre-1983 between Ireland and the

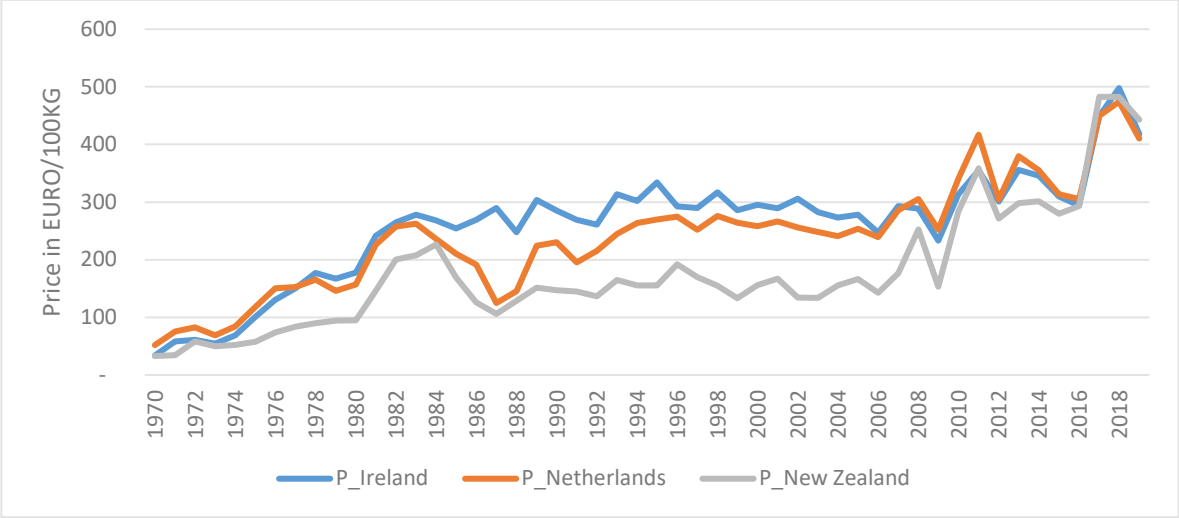


Figure 3. Export butter price for the top three butter exporters in the world. Source: Food and Agriculture Organization Statistical Databases (FAOSTAT).

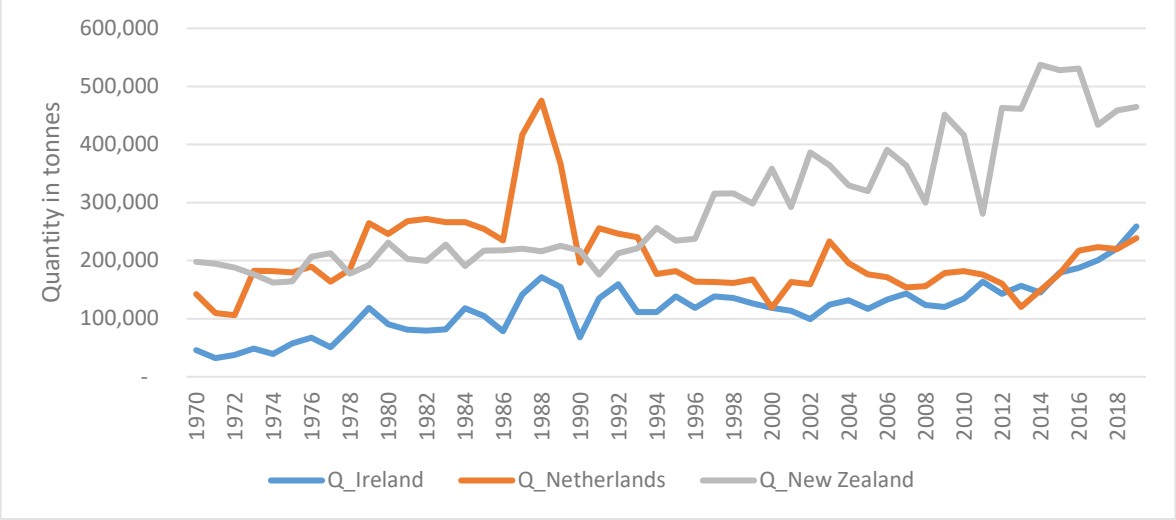


Figure 4. Export butter quantity for the top three butter exporters in the world. Source: Food and Agriculture Organization Statistical Databases (FAOSTAT).

Netherlands, and post-2006 for all countries. This pattern suggests a long-run relationship exists between the selected spatial prices (Fousekis and Trachanas, 2016). Ireland and NZ export prices started drifting apart post-1973 after Ireland joined the EU. Moreover, Ireland and the Netherlands' export prices started drifting apart post-1983, which was a year before the milk quota was introduced in the EU.

The decline of export prices from the Netherlands in 1983 and NZ in 1984 to about 1987 was followed by a significant spike in quantity exported from 1986 to 1988 for the Netherlands and Ireland. According to WTO (1990), this was during a period where there was a rise in world milk production which was not accompanied by an increasing demand and low retail prices. The accumulation of surplus stocks of butter and skimmed milk powder was high (with a large part of exports consisting of deliveries under derogations), then led to a depressive impact on the prices of all dairy products until 1986–1987. Through the milk quotas and agreed minimum export prices, the dairy industry continued to pursue the objective of reducing the proportion of milk used to manufacture butter due to reduced access to traditional markets (i.e. notably in Western Europe and North America) and the lack of secure alternative markets. During that period, depressed market prices for butter were feared because of their adverse effects on sales and prices of other dairy products, notably powders.

Prices were stable from 1989 to 2008 for all three countries, but the quantity for NZ was steadily increasing in that period and significantly surpassed the Netherlands and Ireland. New Zealand had the lowest prices over the years and has been significantly increasing its quantity since 1991, suggesting significant technology advancements or structural adjustments at the processor (and farm) level. Ireland has generally had the highest prices from 1978 to 2006, and had the lowest quantity exported amongst the selected countries but has experienced a significant increase from 2014. According to Hockmann and Voneki (2006), the EU domestic prices were significantly higher than prices on the world market due to the high protection of dairy production in the EU. Through the 90s and 00s, there were export subsidies paid by the EU to bridge the difference between Ireland and NZ prices and these have now been largely removed.

Table 1 presents the annual butter price (€/100 kg) trends in means and standard deviations pre-quota (1970–1983), during (1984–2009) and post-quota (2010–2019). The butter prices have increased significantly from the pre- to post-quota period for all countries. Ireland had the highest average butter price during quota with the lowest standard deviation, suggesting relatively minimal price fluctuations. New Zealand maintained

Table 1. Annual butter price trends pre, during and post-quota

Quota		Pre: 1970–1983	During: 1984–2009	Post: 2010–2019
XP_{IRL}	Mean	140	283	364
	STD	82	23	69
XP_{NED}	Mean	143	240	375
	STD	69	41	61
XP_{NZ}	Mean	91	158	349
	STD	56	30	87

Source: Food and Agriculture Organization Statistical Databases (FAOSTAT).

competitive prices in all periods, but the standard deviation was highest post-quota, highlighting the need for price adjustments due to the rise in competition and policy changes, especially from the EU countries. According to Liu *et al*. (2019), the existence of a pricing regulation slows down the adjustment speed or responsiveness of prices back to the long-run equilibrium. EU policies allowed for higher EU prices above the world price, by preventing competitors to penetrate their markets which was not the case for the US where Ireland was able to outperform the US domestic producers based on price. For example, Newton (2016) argued that an opportunity to arbitrage was unlocked in 2015 by the lifting of the EU milk quota system leading to additional world butter supplies and lower international butter prices which had a negative impact on the US domestic butter market. The combined effect of high US domestic prices and low world prices led to a surge in US imports of butter and butter substitutes in 2015 triggering WTO-authorized butter safeguards to protect US markets. Ireland was and has been amongst the countries that have targeted the US for its butter exports in recent years, especially post quota.

In Ireland, a strategic focus for dairy stakeholders is on the production of high-value dairy products. Donnellan *et al*. (2015) argue that the convergence of Irish milk prices over time with those of the EU is due to greater diversification in the Irish product mix in recent years. The declining trade barriers, intensification of competition and innovations in milk processing has necessitated access to raw material components on a global scale including via imports which can be viewed as a way to secure comparative advantage where demand and supply for butter continue to increase and competition for farm milk is high (Bord Bia, 2020; Fousekis and Trachanas, 2016). According to Newton (2016), dairy commodity imports increase when the difference between domestic dairy product prices and the prices for similar products produced in foreign markets exceed transaction costs. From 1995 to 2013, Irish dairy farmers collectively invested approximately €1.4 billion in the purchase of milk quota to help meet the demand of processors (Donnellan *et al*., 2015). Figure 5 displays the price of milk delivered to processors and butter export prices from 1975 to 2019. The domestic milk price has had a steady increase over the years along with the butter export prices but the milk prices were less responsive to the fluctuations in butter prices from 1991 to 1999.

Figure 6 shows Irish milk production and the ratio of imports to milk production. The quantity of milk produced was stable from 1985 to 2009 due to the milk quota which was introduced in 1984 and abolished in 2015. The discussions for its abolition were introduced in 2008 and from 2009 to 2015 there was a steady relaxation of the restrictions i.e. soft landing period. In 2019, Irish milk production was at a record high at 7.99 billion litres and whole milk imports were about 640 million litres which is equivalent to 8% of the milk produced domestically. The import price captures the cost of importing raw materials (Abeysinghe and Yeok, 1998). Ireland mainly imported milk from Northern Ireland due to the way the processing industry has developed. The rise in the quantity of milk imports coincided with the stabilization of milk import prices which were very volatile before 1989. The significant rise in the quantity of milk imports from 1998 suggests that the milk quota of around five thousand tons for Ireland was not enough to meet the milk demand from processors which was expanding rapidly to meet the export demand of Irish dairy products.

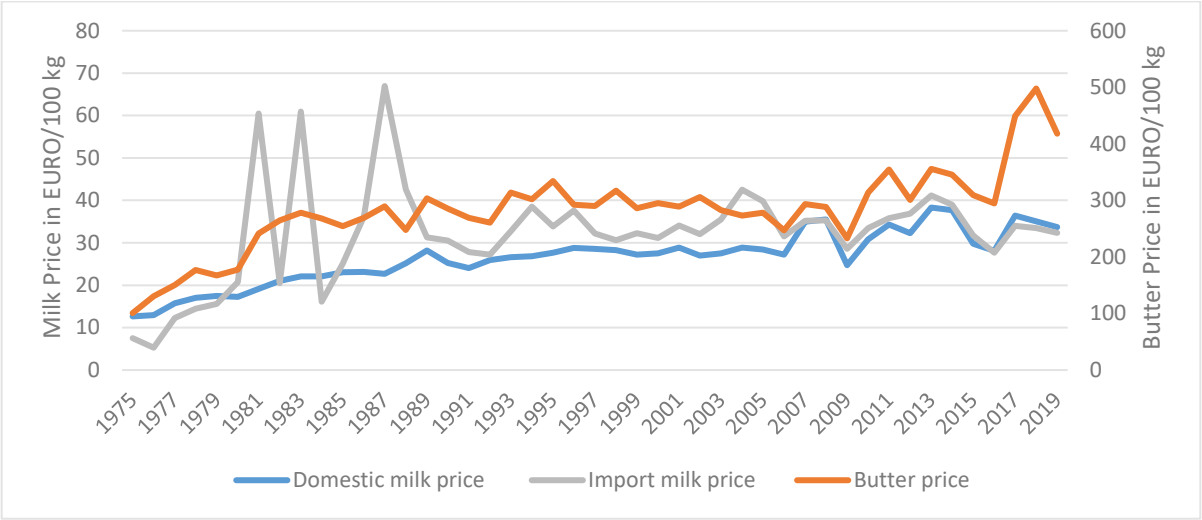


Figure 5. Domestic and imported milk and butter prices in Ireland. Source: Food and Agriculture Organization Statistical Databases (FAOSTAT).

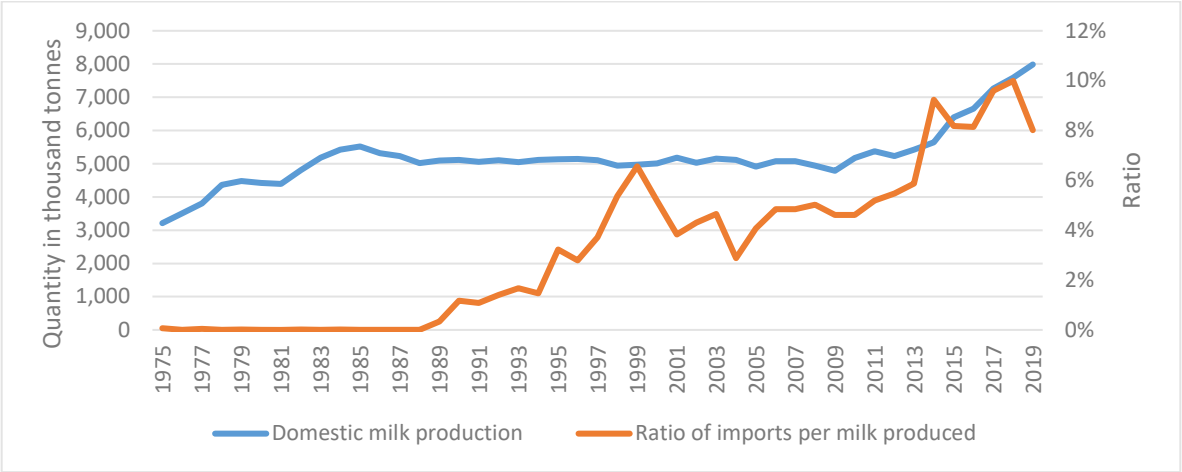


Figure 6. Irish milk production and the ratio of milk imports in Ireland. Sources: Irish Central Statistics Office (CSO) and FAOSTAT.

5. Empirical econometric methods

5.1 Stationarity tests for time series

The data was first transformed by using the (natural) log to help reduce heteroscedasticity and normally distributed errors as well as for ease of interpretation as log changes approximate growth rates and are additive through time (Zhang *et al*., 2017). The logged variables were tested for the presence of unit roots or stationarity using the Augmented Dickey–Fuller (ADF), Phillips–Perron (PP) and the Kwiatkowski–Phillips–Shmidt–Shin (KPSS) tests which deliver complementary results that help to minimize the probability of a type II error (Newton, 2016; Olipra, 2020; Ramsey *et al*., 2021). The ADF and PP unit root tests test the null hypothesis that a time series is non-stationary at level or stationary at first differences and the KPSS stationarity test tests the null hypothesis that a time series is stationary at level. Where the test statistic is statistically significant

for ADF and PP tests, the tested series is stationary and where the KPSS test is significant, it would be non-stationary. Non-stationary time series integrated of order one (I(1)) or stationary at first differences may have at least one co-integrating relationship. If the price time series are stationary, namely integrated of order zero (I(0)) or stationary at level, they can be studied using Autoregressive Distributed Lag models. However, price time series are often non-stationary as their statistical properties change over time. Non-stationary data cannot be predicted and modelled, because the model may be unreliable or spurious. For a consistent and reliable result, the original price time series needs to be transformed into stationary data for model construction, normally by differencing or if the data shows a deterministic trend by de-trending.

5.2 Selection of model between vector autoregressive and vector error correction

The choice of using the vector autoregressive (VAR) and vector error correction (VEC) models depends on the level of integration of variables and residuals in the model. If the variables are I(1) and the residual or error term is I(0), then at least one cointegrating relationship exists and the VEC model is preferred (Enders, 2015). The cointegration and the error correction models (ECM) are based on the idea of a long-run equilibrium, which disallows individual prices from drifting apart in long-term disequilibrium (Ghoshray, 2002; Liu *et al*., 2019). The presence of asymmetries (i.e. due to quota policy) may invalidate the standard tests, such as the Dickey-Fuller test or the Johansen test for cointegration. When there are more than two I(1) variables in the system, the maximum likelihood approach of Johansen and Julius can be used in addition to the residual-based approach of Engle and Granger (Zhang *et al*., 2017). According to Levendis (2018), Engle and Granger's two-step procedure builds on regression, and Johansen's procedure builds on VARs and circumvents many of the problems in the two-step approach. The Granger causality test is undertaken to assess whether a unidirectional or a bidirectional relationship exists between the three main butter producing countries and within the value chain. However, Granger causality is not real causality, it is only statistical causality. The test results support the discussion about the predictive power of one price on another. The relationship derived from the Granger test is used to support the VEC model building that is to disentangle short- and long-run dynamics in price interdependence.

5.3 Key advantages of the VEC model and the estimation strategy

According to Asteriou and Hall (2011), there are four key advantages of using the VEC model. Firstly, it is a convenient model for measuring the correction from the disequilibrium of the previous period, which has a very good economic implication. Secondly, ECMs are formulated in terms of first differences, which helps to resolve the problem of spurious regressions. Thirdly, the VEC model searches for the most parsimonious ECM model that best fits the given data sets with ease. Finally, the disequilibrium error term is a stationary variable. Therefore, the presence of cointegration implies that there is some adjustment process preventing the errors in the long-run relationship from becoming larger and larger. Based on the trends of a time series, the convergence of prices in the long-run would suggest that cointegration exists between the prices. This is what is referred to as the Law of One Price (LOP). For example, butter prices in similar countries should be cointegrated and shouldn't diverge indefinitely (Bergmann *et al*., 2016). They should only be separated by transaction costs i.e. transfer costs (i.e. freight, insurance, tariff rates etc.) and other costs of trade (Serra *et al*., 2006). If they were different, arbitrage would occur leading to exporters buying low and selling high to other countries, taking advantage of the price difference (Chavas and Mehta, 2004; Newton, 2016). The equilibrating role of spatial arbitrage does not come into play when prices differ by less than transfer costs (Norwood and Lusk, 2008). The cointegration models used in this analysis does not require observations of transaction costs (Bakucs *et al*., 2014; Serra *et al*., 2006).

The estimation strategy for this study can be summarized as follows (Asteriou and Hall, 2011; Enders, 2015; Levendis, 2018). The first step was to test whether the individual price series and residuals are stationary and their order of integration using statistical tests and line graphs. The second step was to estimate the long-run relationship and check for the order of integration of the residuals. A co-integrating relationship

among the variables was estimated by ordinary least squares (OLS) and the error term was specified by using lagged residuals from the co-integrating regression. The third step was to estimate the long-run cointegrating equations based on economic theory, as well as the short-run adjustment terms. The results derived from these relationships feed into variables used to estimate a general Johansen multi-equation VEC Model. The fourth step was to estimate the orthogonalized impulse response functions to indicate how a shock or exogenous price impulse to one variable affects the other variables, or to describe the causal effects while ensuring that the ordering is justified based on economic theory (Zhang *et al*., 2017). Lastly, the robustness checks (i.e. for autocorrelation and stability) were performed and several reasonable specifications were tried and compared before selecting the best models.

5.4 VEC model estimation for Irish butter prices

In the long-run, if the relationship between prices is cointegrated, we assume this relationship can be specified as follows (Johansen normalization restriction imposed) using Ireland as the dependent variable.

Horizontal (h) price transmission: $ECT_{IRLh,\,t} = LXP_{IRL,\,t} - \alpha_0 - \alpha_1\, LXP_{NZ,\,t} - \alpha_2\, LXP_{NED,\,t}$ (1)

Vertical (v) price transmission: $ECT_{IRLv,\,t} = LXP_{IRL,\,t} - \beta_0 - \beta_1\, LFMP_{IRL,\,t}$ (2)

This approach is adapted from previous literature, i.e. O'Connor *et al*. (2007); Hockmann and Voneki (2006); Newton (2016); Zhang *et al*. (2017); Liu *et al*. (2019) where ECT is the Error Correction Term, LXP is the logged butter export price for Ireland (IRL), New Zealand (NZ) and Netherlands (NED), LFMP is the logged farm milk price for Ireland, α and β are coefficients and t is for time. The negative sign of the coefficients of the error correction term means their short-term fluctuation can reverse or be pulled back by market forces when moving out of long-term equilibrium. The coefficients of the variables are elasticities and a value greater than one indicates an elastic impact of the variable (Ramsey *et al*., 2021) or price over adjustment. The sign and magnitude of the price transmission elasticity or responsiveness can be related to different underlying economic forces. According to Vavra and Goodwin (2005), price transmission might be asymmetric in its speed and magnitude and could differ depending on whether the price shock is positive or negative and is being transmitted upwards or downwards along the chain.

The VEC model for butter price in three countries with long-run and short-run relationships can be written as follows:
Horizontal price transmission based on annual data:

$$\Delta LXP_{IRL,\,t} = \phi + \sum_{b=1}^{k-1} \delta_b\, \Delta LXP_{IRL,\,t-b} + \sum_{j=1}^{k-1} \psi_j\, \Delta LXP_{NED,\,t-j} + \sum_{m=1}^{k-1} \rho_m\, \Delta LXP_{NZ,\,t-m} + \lambda_1 ECT_{IRLh,\,t-1} \quad (3)$$

$$\Delta LXP_{NED,\,t} = \sigma + \sum_{b=1}^{k-1} \delta_b\, \Delta LXP_{IRL,\,t-b} + \sum_{j=1}^{k-1} \psi_j\, \Delta LXP_{NED,\,t-j} + \sum_{m=1}^{k-1} \rho_m\, \Delta LXP_{NZ,\,t-m} + \lambda_2 ECT_{NEDh,\,t-1} \quad (4)$$

$$\Delta LXP_{NZ,\,t} = \vartheta + \sum_{b=1}^{k-1} \delta_b\, \Delta LXP_{IRL,\,t-b} + \sum_{j=1}^{k-1} \psi_j\, \Delta LXP_{NED,\,t-j} + \sum_{m=1}^{k-1} \rho_m\, \Delta LXP_{NZ,\,t-m} + \lambda_3 ECT_{NZh,\,t-1} \quad (5)$$

Vertical price transmission based on monthly data:

$$\Delta LXP_{IRL,\,t} = \beta + \sum_{q=1}^{k-1} \delta_q\, \Delta LXP_{IRL,\,t-q} + \sum_{s=1}^{k-1} \psi_s\, \Delta LFMP_{IRL,\,t-s} + \lambda_4 ECT_{IRLv,\,t-1} \quad (6)$$

$$\Delta LFMP_{IRL,\,t} = \Omega + \sum_{q=1}^{k-1} \delta_q\, \Delta LXP_{IRL,\,t-q} + \sum_{s=1}^{k-1} \psi_s\, \Delta LFMP_{IRL,\,t-s} + \lambda_5 ECT_{IRLv,\,t-1} \quad (7)$$

where Δ denotes changes in first differences, δ_b, ψ_j, ρ_m, δ_q, and ψ_s are short-run coefficients of the models' adjustment to long-run equilibrium. λ is the speed of adjustment parameter with a negative sign. ECT_{t-1} is the error correction termed lagged value of the residuals obtained from the cointegrating regression of the dependent variable on the repressors. It is based on the notion that the deviation from long-run equilibrium in

the last period will influence its short-run dynamics. *k*—1 is the optimal lag length which is reduced by one. The lags can be due to contracts, imperfect information, sticky prices, long-term buyer-seller relationships and inertia in consumer habits which may cause prices to deviate in the short run from equilibrium, but in the long-run these deviations should be eliminated (Ghoshray, 2002). The differences analysis removes the effect of standard cost components from the analysis.

6. Findings and Discussions

Table 2 presents the unit root tests (ADF and PP) and stationarity test (KPSS) statistics for butter prices in three countries and Irish farm milk prices. The unit root tests results were generally consistent with each other, especially for first differences. The variables were all stationary for first differences at a 5% significance level based on the KPSS test.[1] The unit root tests were consistent with the stationarity test at first differences. Given the same order of integration (I(1)) based on the unit root and stationarity tests, the focus was on the logged variables which have coefficients that can be interpreted as elasticity. The OLS estimates of the cointegrating relationship regressions (for horizontal and vertical price transmission) indicated that the residuals were all stationary at level or integrated of order zero (I(0)) at 5% significance level, based on ADF and PP tests. The additional or full output of the residual statistics or results for horizontal and vertical price transmission cointegrating relationship regressions can be made available upon request. These findings suggested that there were cointegration or long-run economic relationships between prices both horizontally and vertically which implied that prices moved closer together in the long-run, although in the short-run pre quota abolition they may have drifted apart. Therefore, given the results of the stationarity tests, the estimation of the VEC models for price transmissions or causal relationships was warranted. The test statistics between the monthly butter and milk prices suggest that the butter prices were more stable than the milk prices which were relatively more volatile. This difference in volatility can be explained by the perishability of the product and opportunity to store the product for certain period until prices become favorable.

Table 2. Unit root and stationarity tests statistics for farm milk and butter prices

	PP	**ADF**	**KPSS**
Logged			
LXP_{IRL}	−5.2***	−4.23***	0.47**
ΔLXP_{IRL}	−7.5***	−7.46***	0.36
LXP_{NED}	−2.99**	−2.87***	0.57**
ΔLXP_{NED}	−6.95***	−6.81***	0.27
LXP_{NZ}	−1.89	−1.94	0.55**
ΔLXP_{NZ}	−6.95***	−7.7***	0.17
Monthly data			
LXP_{IRL}	−3.1**	−1.95**	0.07
ΔLXP_{IRL}	−7.87***	−7.73***	0.04
$LFMP_{IRL}$	−1.7	−1.73**	0.33***
$\Delta LFMP_{IRL}$	−12.97***	−12.95***	0.04

Note(s): ***1%; **5%; ADF critical values with drift were used with 2 lags. KPSS with no trend at a maximum lag of 10 as chosen by Schwartz criterion. Statistical significance for the KPSS test indicates the non-stationarity of the variable.

[1] According to Hobijn *et al*. (2004) and Kagalwala (2022), the challenge of KPSS in STATA is that it uses asymptotic critical values and does not consider the sample size which can be a problem for short time series (low power). One way to respond to this is to report results for the 5% significance level, especially for a time series below 50 (Ramsey *et al*., 2021).

Table 3 shows VEC results of the horizontal and vertical price transmission effects or Granger causality effects between prices in the long-run (asymmetry in magnitude). For horizontal price transmission, the NZ prices had a positive elastic impact (elasticity is >1) at a 5% significance level, i.e. asymmetric price adjustment effects, on Irish prices in the long-run. For example, a 1% increase in NZ prices led to a 1.33% increase in Irish prices, *ceteris paribus*. This finding is not surprising since the quantity of butter exported for Ireland was capped around one hundred thousand during the quota period, indicating an inelastic supply for Irish butter and an elastic supply for NZ butter. Consequently, to compete, Irish butter prices had to increase more to maintain or improve its profitability and to keep up with the increasing international demand for Irish butter. Liu *et al*. (2019) found that both market power and state pricing regulations contribute to the heterogeneity in asymmetric price transmission. There was a bidirectional causality relationship that occurred between NZ and Ireland for butter prices, but Irish prices had a positive inelastic impact on NZ prices. A study by Olipra (2020) found that exporting countries with the highest market shares in dairy products effectively set the world price while other exporters were adjusting their prices. The findings in our study suggest that this relationship is not always unilateral, even though the impact of smaller countries might be smaller on bigger countries. Hockmann and Voneki (2006) and Bergmann *et al*. (2016) found that the EU, as a region, was able to affect world market prices because of its subsidized exports and its high share of butter export. However, they did not specify which of the EU countries had an impact on NZ, as identified in this study. There was a unidirectional causality relationship that occurred from Ireland to the Netherlands. Irish prices had a negative inelastic impact at a 5% significance level on the Netherlands prices in the long-run, *ceteris paribus*.

For vertical price transmission in the long-run, in Ireland, there was a bidirectional causality relationship that occurred from butter prices to farm milk prices and vice versa. Butter prices had a positive inelastic impact on farm milk prices, significant at the 1% significance level, i.e., 1% increase in butter prices resulted in a 0.62% increase in farm milk prices, *ceteris paribus*. Farm milk prices had a positive elastic impact on butter prices, significant at the 1% significance level, i.e., 1% increase in farm milk prices resulted in a 1.66% increase in butter prices, *ceteris paribus*. Given the limitations in the quantity that could be produced for butter and farm milk, a lot of policy emphasis was on the price changes to ensure profitability for processors and farmers, and to help reduce risks for them while maintaining a competitive industry. Bakucs *et al*. (2014) found that limits imposed on the price competition between retailers may lead to stronger pressure to use a vertical pricing policy to increase market share. The findings suggest that butter prices or processors derived more value from farm milk prices than they provided to farmers, potentially due to the higher risk that processors face from increasing input costs, especially with the presence of bigger international competitors for butter. This could also suggest the influence of other dairy commodities on farm milk prices and their competition for farm milk. However, that influence might have been offset by the fact that farmers benefit from higher

Table 3. Price transmission effects between prices in the long-run

Variable	$LXP_{IRL, t}$	$LXP_{NED, t}$	$LXP_{NZ, t}$	$LFMP_{IRL, t}$
Horizontal price transmission (annual)				
Constant	5.56	4.68	−4.18	
$LXP_{IRL, t}$		−0.84**	0.75*	
$LXP_{NED, t}$	−1.19		0.89*	
$LXP_{NZ, t}$	1.33**	1.12***		
$ECT_{h, t}$ (χ^2)	7.39**	12.5***	91.25***	
Vertical price transmission (monthly)				
Constant	2.77***			−1.7***
$LXP_{IRL, t}$				0.62***
$LFMP_{IRL, t}$	1.63***			
$ECT_{v, t}$ (χ^2)	47.57***			20.18***

Note(s): ***1%; **5%; *10%.

commodity prices through dividends from processors, since most Irish dairy farmers sell into a co-op structure. Therefore, it is not possible in this study to conclude that the "weaker" parties in the food chain incur most of the burden of adjustment without the assessment of the impact that other dairy commodities (with heterogeneity in their strategic behaviors) have on-farm milk price, even though the findings suggest that to be the case. As noted by McCorriston (2015), at best the time series approaches using pairs of price series represent a 'first-pass' test relating to the functioning of the food chain since it is difficult to ascertain from this framework what factors are likely to be driving the results.

Table 4 presents the horizontal and vertical price transmission for butter and milk prices in the short-run (asymmetry in speed) and cointegration equations. The coefficients of the error correction terms with a negative sign capture the short-term fluctuations being pulled back by market forces when moving out of long-term equilibrium and it directly measures the speed at which the price in one region reacts to deviations from long-run equilibrium after a price change in other regions (Asteriou and Hall, 2011). Focusing on horizontal price transmission, the growth rate of Irish butter prices tended to adjust to deviations from the equilibrium growth rate at a faster speed than the growth rate of the Netherlands butter prices, with average growth rate response or speed of adjustment to long-run disequilibrium of 17% and 12%, respectively. The lagged growth rate of butter prices for the Netherlands and NZ had a positive impact at a 5% significance level and a negative impact at a 1% significance level, respectively, on the growth rate of Irish butter prices in the short-run, *ceteris paribus*. For vertical price transmission, the monthly growth rate of Irish butter prices tended to adjust to deviations from the equilibrium growth rates at a slower speed than the growth rate of milk prices, with average growth rate response or speed of adjustment to long-run disequilibrium of 2 and 9%, respectively. The speed of adjustment was more rapid on horizontal than vertical price transmission. In other words, Irish butter prices were quick to respond to international price changes than to local price changes which are expected since the bulk of Irish butter is mainly for the export market and commodity prices dictate milk prices. Serra and Goodwin (2003) and Liu *et al*., (2019) found that policymakers can cause retailers or processors to be less responsive to farm price changes, even though their laws intend to protect farmers.

Figure 7 displays a visual representation of the effects of price shocks (impulse response) and their duration over time. Impulse response functions provide a visual overview of the dynamic price patterns associated with a one-time shock in a price series. In cointegrating VECM, it is expected that the impulse response functions or the effects of some shocks will not die out over time because the I(1) variables are not mean reverting as in VAR or reflecting the nonstationary nature of the price data (Serra and Goodwin, 2003). According to McCorriston (2015), the long-lasting change in prices matters for macroeconomic policy and

Table 4. Price transmission in the short-run (asymmetry in speed).

Variable	$\Delta LXP_{IRL, t}$	$\Delta LXP_{NED, t}$	$\Delta LXP_{NZ, t}$	$\Delta LFMP_{IRL, t}$
Horizontal price transmission (annual)				
Constant	−0.01	−0.002	0.03	
$\Delta LXP_{IRL, t-b}$	−0.24	−0.12	0.31	
$\Delta LXP_{NED, t-j}$	0.48**	0.24	0.25	
$\Delta LXP_{NZ, t-m}$	−0.35***	−0.18	−0.4**	
$ECT_{h, t-1}$	−0.17***	−0.12*	−0.05	
Vertical price transmission (monthly)				
$\Delta LXP_{IRL, t-q}$	0.03			0.21
$\Delta LFMP_{IRL, t-s}$	0.02			0.59***
$ECT_{v, t-1}$	−0.02***			−0.09***

Note(s): ***1%; **5%; *10%.

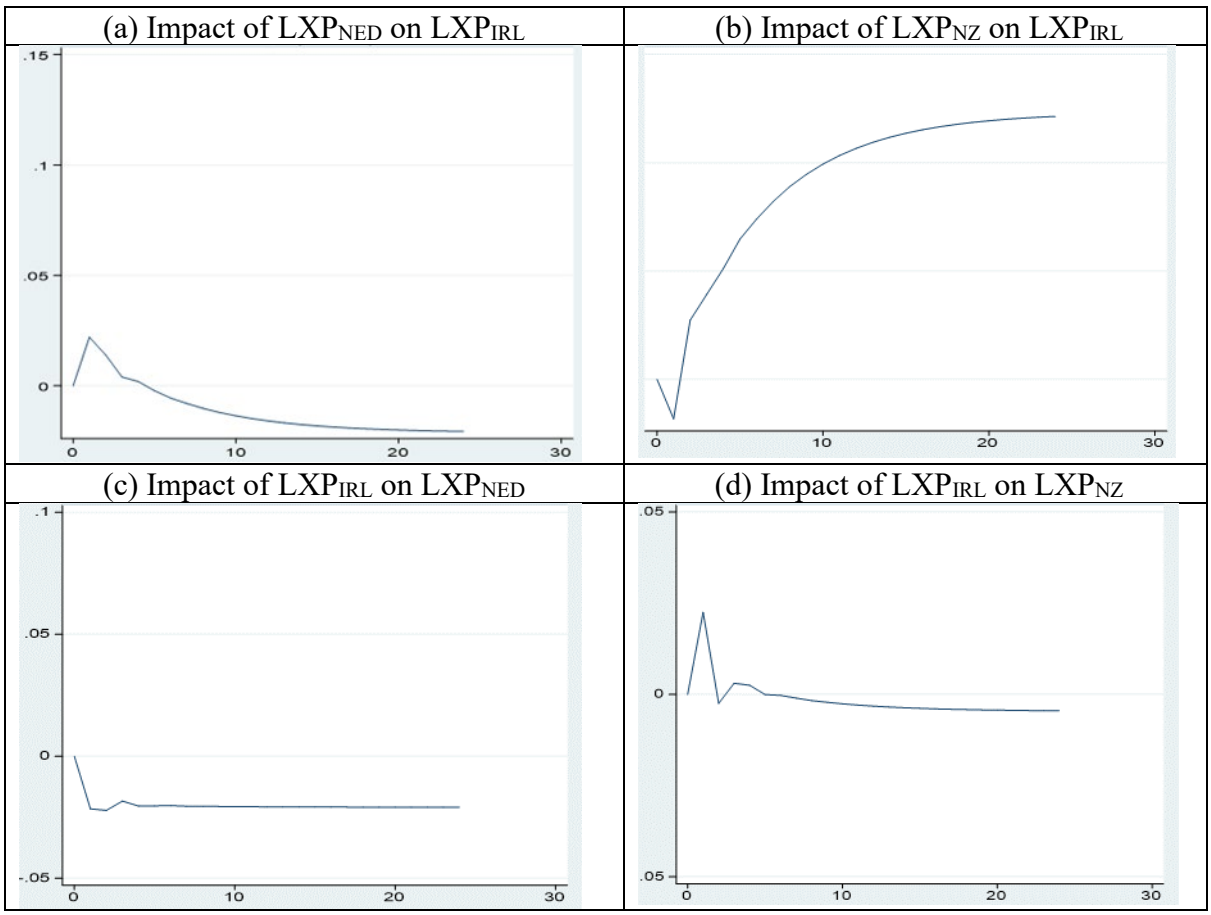


Figure 7. The effects of price shocks. Note: the *x*-axis is the period after a shock and the *y*-axis is the magnitude of the impulse response.

may lead to governments prioritizing actions to moderate the impact of price spikes on world markets. On the other hand, imposing policy on transitory events may only result in output volatility. The graphs presented in Figure 7 are consistent with the findings in Tables 3 and 4, and the overall effects of the price shocks were permanent at different rates, except for Figure 7(c) for the impact of Irish butter prices on the Netherlands butter prices. The Netherlands prices had a positive short-term shock on Irish butter prices, but their impact slightly declined below zero in the long-run as shown in Figure 7(a). Ghoshray (2002) found that countries exporting lower quality commodities may have to lower prices more rapidly than countries that export higher quality commodities, i.e. due to technological advances, economic investments and government policies, to retain market share.

The NZ butter prices had a negative short-term shock on Irish butter prices, but their impact significantly increased way above 10% in the long-run as shown in Figure 7(b). The opposite effects of the Netherlands and NZ on Irish butter prices can be explained by the nature of competition between the countries. For example, within the EU, the Netherlands and Ireland are governed by the same policies and trade in the international markets as a bloc. On the other hand, NZ remains the main competitor for Ireland as indicated by the significant influence on its prices. As noted by Fousekis and Trachanas (2016), when import demand and trade are booming and stocks are tight (i.e. due to quota restrictions in the EU), exporters have a stronger incentive to match a price increase from their competitors rather than a price decrease due to the increase in the intensity of competition. This is was found to be true for Ireland in the long-run instead of short-run due to lags, concerning NZ butter prices.

7. Conclusion and areas for future research

The CAP policy was initially established to ensure transmission of pricing benefits from the dairy commodity markets to farmers and dealing with external competitors within the EU. Given the high level of market integration and competitive pricing in the international butter market, Ireland was susceptible to spatial price arbitrage and was protected by CAP policy. During the quota period, Ireland had the highest butter prices and was limited in terms of being able to increase quantity which meant that it could not expand in existing and new markets by repositioning its products from existing markets such as the US. At the same time, NZ was able to significantly increase its quantity exported within the same price range. Ireland was limited to competing through prices in the international butter market, raising the significance of butter input prices, i.e. farm milk prices, on butter prices. The empirical results provided evidence of asymmetric price transmissions for the Irish butter market in the whole value chain.

The Irish butter prices were more responsive to NZ butter prices and farm milk prices in the long-run with positive bidirectional causality effects horizontally and vertically, respectively. Declining world milk prices and product age (perishability and storability of the product) may prevent symmetric response of Irish milk prices to changes/shocks in Irish butter prices. Moreover, different target markets and EU or NZ policy for Irish and NZ butter may prevent symmetric response of Irish butter prices to changes/shocks from NZ butter prices. Irish dairy farmers and processors were more susceptible to pricing decisions made by international butter processors with asymmetric price transmission i.e. not realizing the full benefit from changes in international butter prices as price takers. The farm milk prices were not insulated from the price shocks in the international butter markets but they were slow to respond to butter price changes. Ireland had a relatively lower market share compared to NZ and was restricted by the EU milk and butter regulations, but these dynamics could change in future as Ireland continues to expand its butter production in the post-quota era.

Future policies and pricing strategies that seek to ensure competitive price positioning and risk management (price resilience) for Irish butter prices need to consider the long-run and short-run effects of international competitor prices and milk prices identified in this study. Considering the nuances that exist at the regional or EU level, whereby a one size fits all approach, might not be best for some countries or sectors that have different production mixes of dairy products. This paper contributes to the objectives of the Food Wise 2025 policy by examining milk and butter prices to help minimize risks for processors and gives farmers confidence regarding price transmission. It will also help to enhance the engagement between processors, producers and the government to make informed decisions. Our empirical findings present an opportunity for improving our conceptual understanding of the dynamic butter price adjustments within the value chain. Ireland was able to increase its butter prices above competitor prices due to EU regulations that governed the EU dairy market, suggesting their effectiveness in maintaining barriers to entry in the EU. However, the effects of this on the Irish butter competitiveness (without the protective regulations) and processor profitability remain an area for future research, i.e. linking prices to costs and profit margins for products at the various stages of the value chain. Future research can also analyze the impact of competitor butter prices in importing countries, i.e. the US, on Irish butter prices in those markets, and identify the forces driving competition in the butter market for importing countries, especially pre and post-quota. The approach followed in this paper can be adapted for other sectors, i.e. cheese and/or powders.

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