Measuring the Effects of Technology Change in Multiple Markets : Application to the Greek Cotton Yarn Industry

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2009

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By

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Abstract

Complications arise in the estimation of welfare changes in vertically and horizontally linked markets when technology affects production. Past research has dealt with these complications using single-equation models and dual approaches. We briefly discuss some of the limitations of these approaches, which include the single-equation approach's poor statistical reliability, and the dual approach's difficulties in incorporating expectations, dynamics, and expert advice. We propose a method that adapts Just, Hueth, and Schmit'z (2004) partial-equilibrium sequential integration approach to the case of prices changing because of technological change. Our approach addresses some of the limitations of the single-equation and dual approaches. Our methods can be applied to the estimation of welfare changes in either vertically or horizontally linked markets, when technology improvements and policy-induced multiple price changes affect the markets. This is a common occurrence in economic problems related to the estimation of welfare changes in agricultural and industrial commodities. We apply our method in an empirical study of the vertically linked market for Greek cotton.

Keywords: Single-Market Approach, Dual Approach, Multi-Market Approach, Technology, Bootstrap

JEL: D6, F1, C0

*Bullock and Dadakas share lead authorship.

**Thanks to Julian Alston, Richard Just, and Carl Nelson for discussions about dual approaches to measuring technology change.

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Abstract

Technology changes in one market often lead to price changes in other markets. For example, such price changes can occur when markets are horizontally linked through demand substitutability or complementarity, or vertically linked through input and output market relationships. But the existing literature on the welfare effects of technological change often fails to consider that technological change in one market can change prices in other markets. Two methods of measuring the (producer) welfare effects of technological change appear in the literature. The first, which Alston, Norton, and Pardey (1998, p. 505) call the "single-equation supply" method, involves estimating the sizes of geometric areas behind the supply curves in the market directly affected by the technology change. Alston, Norton, and Pardey (1998) present both the theory that underlies the single-equation supply methodology, and a thorough discussion of its application. Griliches, (1957, 1958) used this method in his studies of the welfare effects of hybrid corn technology. Scores of articles have followed; fairly recent examples are Giannakas and Fulton (2000); Moschini, Lapan and Sobolevsky (2000); Gotsch and Burger (2001); Perrin and Fulginiti (2001); Berwald, Carter, and Gruyère (2006); Demont, Oehmke and Tollens (2006); Frisvold, Reeves, and Tronstand (2006); and Hareau, Mills, and Norton (2006). Older articles using the single-equation approach to examine welfare changes from technology or policy are Babcock and Foster (1992), Cooke and Sundquist (1993), Gisser (1993), Constantine, Alston, and Smith (1994), Byerlee and Traxler (1995), McCorriston and Sheldon (1994), Moschini and Sckokai (1994), Schmitz, Boggess, and Tefertiller (1995), Sumner and Wolf (1996), and Minot and Goletti (1998).

For reasons to be explained, we will sometimes refer to the single-equation supply method of measuring the welfare effects of technological change as the *shutdown price* method, where here we use a term from Just, Hueth, and Schmitz's (2004, pp. 78-81) analysis of changes in multiple prices without a technology change. A well-recognized limitation of the shutdown price method is that the estimates derived from the method can lack statistical reliability. This occurs because with the shutdown price method it is often necessary to extrapolate the econometric estimation of the supply function to regions outside the range the data. Just, Hueth, and Schmitz (2004, pp. 284-292) have provided a helpful discussion.

Dual approaches provide the second method of estimating the producer welfare effects of technology change. Dual approaches have frequently been used in agricultural economics to estimate various technology parameters, for example the factor biases of technology change (e.g., Belinfante 1978; Antle 1984; Coelli 1996). But fewer studies have used dual approaches to estimate the effect of technology change on producer welfare (Shumway, 1983).

The dual approach and the single-supply equation approach have their own advantages and disadvantages. The limitations presented in dual and single-supply approaches guide our own theoretical/empirical work. We adapt a partial-equilibrium, multi-market, sequential integration approach which allows us to measure the welfare effects of technological change in markets where price-interrelations exist. We concentrate on the estimation of producer welfare changes in the vertical market for Greek cotton and adapt our model so that it allows us to estimate the combined effects of technology advances and input/output price changes on the welfare of producers within vertically linked markets. We then discuss how ignoring the effects of technology may bias the results. Our approach can capture expectations, it does not extrapolate estimations outside the range of the available data, and it does not require the estimation of a profit function or a cost function. Our approach can deal with the complexity of the price-interrelations in the markets affected by technological change. Moreover, our approach can be adapted to the study of various economic problems where vertical and/or horizontal markets result in price-interrelations between the markets and technology is an important factor. Expert advice about the size of economic curve shifts is easily incorporated with our approach. This is the case with many economic problems related to industrial and agricultural economics.

While there are scores of articles in the literature that employ the single-equation supply method, articles that examine or provide applications of multi-market theory are fewer. Examples of general equilibrium multi-market studies are presented by Thurman (1991), Thurman and Wohlgenant (1989), Thurman and Easley (1992), Bullock (1993b), Canning and Vroomen (1994), and Brannlund and Kriström (1996). Examples of the partial equilibrium multi-market approach which we employ in this study, other than the main contributions by Just and Hueth (1979) and Just, Hueth, and Schmitz (1982; 2004) who developed the theory, are limited and include European Commission (2000), Gillig, Griffin, and Ozuna (2001), Jeong, Garcia and Bullock (2003), and Dadakas and Katranidis (2008; 2010). None of these studies however incorporate the effect of technology in the analysis.

2. Background of the Markets we Study

We study the vertical market for Greek cotton that consists of the market for cotton yarn (final market) and the market for labor input (intermediate market). The Greek cotton yarn industry has gone through major changes over the last three decades. A quota regime that had been in place since 1974 (Multi Fiber Agreement – MFA, 1974-1994) was gradually phased out in an attempt to liberalize trade for textile and clothing

(T&C) products. Discussions about trade liberalization started during the GATT Uruguay Round negotiations (1987), and were completed by 1995 with the signing of the Agreement on Textiles and Clothing (ATC, 1995-2005). The ATC required the elimination of quota restrictions, which were still in place from the MFA regime, by the year 2005. Fifty one percent (51%) of existing quotas were to be eliminated gradually by the end of 2004, and the remaining 49%, all at once, on January 1, 2005[1].

The ATC affected cotton yarn producers' welfare in most developed countries. World prices for T&C products decreased, and countries with low labor costs were able to exploit significant comparative advantage in the production of T&C products. These developments also affected Greek producers of cotton yarn, who experienced a substantial reduction in production, exports and domestic prices of their products, which plummeted as early as 1987. Historically, domestic prices stood higher than the respective international ones[2]. The gap between domestic and international prices narrowed and producers lost part of the surplus that was annually transferred to them during the MFA regime. The effect of the narrowing gap in domestic vs. international prices is the first component of the welfare effect that our model captures.

Other international developments, not related to the liberalization of trade in T&C products, caused Greek producers to also face a widening gap between the domestic and international cost of labor[3]. Greece's labor costs were triple those of other major yarn exporting countries during the period of our study. The increasing gap between

[1] When the ATC was nearing its 2005 completion and most of the quotas were already released competition intensified. Producers found themselves struggling to compete in the international markets as exports from China grew by 100%. Taking advantage of China's WTO accession agreement, both the US and the EU restricted the rate of growth until the year 2008. The EU came to an agreement with China whereas the US imposed import growth quotas, thus allowing for a more gradual transition towards free trade.

[2] International prices for cotton yarn are defined as the export weighted average export-price of the 8 highest-volume, yarn-exporting countries in the world.

[3] The international cost of labor is defined as the export-weighted cost paid to labor in the world's eight highest-volume yarn exporting counties.

domestic and international labor costs is the second component that we must account for with our welfare change measure. As the gap historically increased, i.e. as domestic prices became relatively higher, the competitiveness of Greek producers in the international markets was weakened[4].

Apart from the changing prices of yarn and labor, cotton yarn producers' welfare was also affected by the adoption of new technologies. During the last three decades significant advances were made in the production of T&C products. When the discussions for trade liberalization started in 1987, producers realized they would have to confront lower prices and increased competition for their products in international markets, so they invested heavily in new technologies. Some segments of the textile industry were automated with the use of precision cutters, and investments were also made in new machinery.

Automation and investment characterized the T&C industry not only in Greece but in most developed countries as well. Characteristic of the R&D is the case of the US, where segments such as industrial fabrics, carpets and specialty yarns were completely automated. Investment in biotechnology research was leading the way to new sources of fibers, such as corn, and to improvements in existing fibers. Some fibers introduced had built-in memories of color and shape, as well as antibacterial qualities (US Department of Labor). Innovations allowed countries such as the US and the EU to compete with low-labor cost countries in the international markets specializing in segments of T&C products that can be completely automated.

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[4] The other major input in the production of cotton yarn is cotton lint. In the market for cotton lint there is no intervention so there is no gap between domestic and international prices, throughout the period we study. Consequently, there is no welfare effect to producers of cotton yarn as a result of policy changes in the cotton lint market. We discuss the exclusion of this market from the analysis and the implications/necessary assumptions in the sections that follow.

The diffusion of technology benefited producers in Greece, as well as producers in other cotton yarn exporting countries. The important role of R&D suggests that a model for the estimation of welfare changes that does not include the effects of advancing technologies might provide biased estimates, especially after 1987, when heavy investments and research characterized the industry.

Each one of these three concurrent developments had an impact on the welfare of producers of Greek cotton yarn. First, producers suffered losses from the decrease in the gap between domestic prices and international prices of yarn, which was a direct effect of trade liberalization. Second, domestic wages increased relative to the respective international wages. These increases are tied to domestic and international policies but are not tied to the liberalization of trade. Domestic producers lost competitive gains from the increase in the gap between the domestic and international costs of labor. Third, producers benefited from the changes in production technologies, which decreased their costs.

3. Theory: An Application to the Vertical Market for Cotton Yarn

Complications arise in the estimation of the welfare changes due to the combined nature of the price changes and the linkages that exist in the vertical market for yarn, cotton lint, and labor. In this section, we use line integral theory to compare the two existing methods of measuring the producer welfare effects or technological change, and then we present a new method of addressing the challenge.

3.1. Using Line Integral Theory to Understand the Challenge at Hand

We start with the representative producer's maximization problem. We use a superscripted index, k = 0, 1, where k = 0 denotes an initial state of trade protection, relatively low Greek labor costs, and an original technology, and k = 1 denotes a subsequent state with liberalized trade, relatively high Greek labor costs, and a new technology. The producer solves the following profit maximization problem:

$$\max_{q_c, q_l} p_y^k f_y\left(q_c, x, T^k\right) - p_c^k q_c - w_l^k q_l \quad ,$$

where p_y^k is the price of cotton yarn, f_y is the cotton yarn production function, p_c^k is the price of cotton lint, w_l^k is labor's wage, q_c is the quantity of cotton lint, q_l is the yarn producers' demand for labor, and T represents technology. As labor demanded by the Greek cotton yarn industry makes up only a small fraction of the total demand for labor in Greece (or even more narrowly defined, industrial labor) we can safely assume that any changes in demand from the cotton yarn industry did not impact wages. The solution to the profit maximization defines a (maximized) profit function $\Pi\left(p_y^k, p_c^k, w_l^k, T^k\right)$, a yarn supply function $q_y^s \;\; p_y^k, p_c^k, w_l^k, T^k$, a cotton lint derived demand function $q_c^d \;\; p_y^k, p_c^k, w_l^k, T^k$, and a yarn producers' derived demand for labor function $q_l^d \;\; p_y^k, p_c^k, w_l^k, T^k$, all for k = 0, 1.

Due to the changes in prices from $\left(p_y^0, w_l^0\right)$ to $\left(p_y^1, w_l^1\right)$ and the annual improvements in technology from T^{i-1} to T^i for any given year, the change in quasi-rents is equal to,

(1) $\Delta\Pi = \Pi\left(p_y^1, p_c^1, w_l^1, T^i\right) - \Pi\left(p_y^0, p_c^0, w_l^0, T^{i-1}\right)$,

which can be expressed by the following:

(2) $\Delta\Pi = \Pi\left(p_y^1, p_c^1, w_l^1, T^i\right) - \Pi\left(p_y^0, p_c^0, w_l^0, T^{i-1}\right) =$

$$\int_C \left(\frac{\partial \Pi}{\partial p_y}\left(p_y, p_c, w_l, T\right) dp_y + \frac{\partial \Pi}{\partial p_c}\left(p_y, p_c, w_l, T\right) dp_c \right.$$

$$\left. + \frac{\partial \Pi}{\partial w_l}\left(p_y, p_c, w_l, T\right) dw_l + \frac{\partial \Pi}{\partial T}\left(p_y, p_c, w_l, T\right) dT \right).$$

The right-hand side of (2) is a line integral, with C being an *arbitrary* piecewise smooth path of integration in $\Re^4$, with endpoints $\left(p_y^0, p_c^0, w_l^0, T^{i-1}\right)$ and $\left(p_y^1, p_c^1, w_l^1, T^i\right)$ (Kaplan 1984, pp. 292-293, especially equation (5.48)). The challenge in empirical work is estimating the quantity represented on both sides of equation (2). The first two integrals on the right-hand side are estimable via econometric analysis of supply and demand function, since by Hotelling's lemma the $\frac{\partial \Pi}{\partial p}(\cdot)$ and $-\frac{\partial \Pi}{\partial w}(\cdot)$ functions are identical to output supply and derived input demand functions. Assigning a value to the third integral is more involved. The chief difficulty is estimating the term $\frac{\partial \Pi}{\partial T}(\cdot)$, which is the marginal effect of a technology change on profits with prices held constant. Hotelling's lemma is of no help in the estimation of $\frac{\partial \Pi}{\partial T}(\cdot)$.

3.2 Three Approaches to Addressing the $\frac{\partial \Pi}{\partial T}(\cdot)$ Term

Two methods have been used in the literature to address the problematical $\frac{\partial \Pi}{\partial T}(\cdot)$ term discussed in the previous section: the dual approach and the single-equation (or "shutdown price") approach. Next we discuss those approaches, then offer a third approach, which has advantages over the other two approaches in certain circumstances. We call this approach the sequential approach.

3.2.1 The Dual Approach

The dual approach provides one conceivable way to estimate the $\frac{\partial \Pi}{\partial T}\cdot$ term. To estimate $\frac{\partial \Pi}{\partial T}\cdot$ econometrically with a dual approach, it is generally not sufficient to simply estimate input and output share functions. Rather, it is necessary to estimate a system of equations involving the $\Pi(\cdot)$ function itself along with the share functions. But this is rarely done in applied studies, perhaps due to data limitations, or perhaps due to doubts that economic profits can be accurately observed in the data by subtracting accounting revenues minus accounting costs. More frequently, cost function approaches are used to estimate systematically the input demand and output supply functions, and at times the cost function itself has been used in the estimation process. But in general the cost function itself is not estimated with the input demand equations, again perhaps due to lack of confidence that economic costs can be well captured by observed accounting costs.

In general the dual approach offers various advantages in estimating output supply and input demand functions. These advantages are well documented in the literature. For our particular case of estimating the welfare effects of technological change, an advantage of the dual approach is that it does not require estimation of output supply or input demand functions well beyond the observed ranges of the prices and quantity data. The single-equation approach often does require this, as we will discuss.

3.2.2 The Single-equation (or Shutdown Price) Approach

This difficulty in econometric estimation is an important reason why empirical studies in agricultural economics have only rarely attempted to use dual approaches to estimate the producer welfare effects of technological change. Instead, as we will explain, the conventional method of dealing with the non-observability of the $\frac{\partial \Pi}{\partial T}(\cdot)$ term has been to take the line integral in (2) over a "shutdown price path of integration," which is illustrated in the top panel of figure 1. The endpoints of any path of integration used must be (p^0, w^0, T^0) and (p^1, w^1, T^1), which are points *G* and *H*. A convenient path of integration is the one defined parametrically by functions $p(t)$, $w(t)$, and $T(t)$ in the bottom panel, which generate a path in which one variable changes at a time, while all others are held constant. The path so defined is made up of four "straight-line" sub-paths, S_1, S_2, S_3, and S_4. Because along sub-paths S_2 and S_3 the output price is zero, if we assumed this causes the firm to shut down[5], then we can assume $\frac{\partial \Pi}{\partial T}\left(p_y, p_c, w_l, T\right)$ is zero all along these sub-paths. Along sub-paths S_1 and S_4, the technology level remains constant. In essence, by taking the convenient "shutdown" path of integration, we have gotten rid of the problematical term $\frac{\partial \Pi}{\partial T}\left(p_y, p_c, w_l, T\right)$.

[5] This scenario implies that a firm's major source of revenues originates from the output product for which prices have dropped below a critical value. The existence of a shutdown price in the Greek cotton-yarn industry is a realistic assumption as cotton-yarn products was the main output for most of the firms active in the sector.

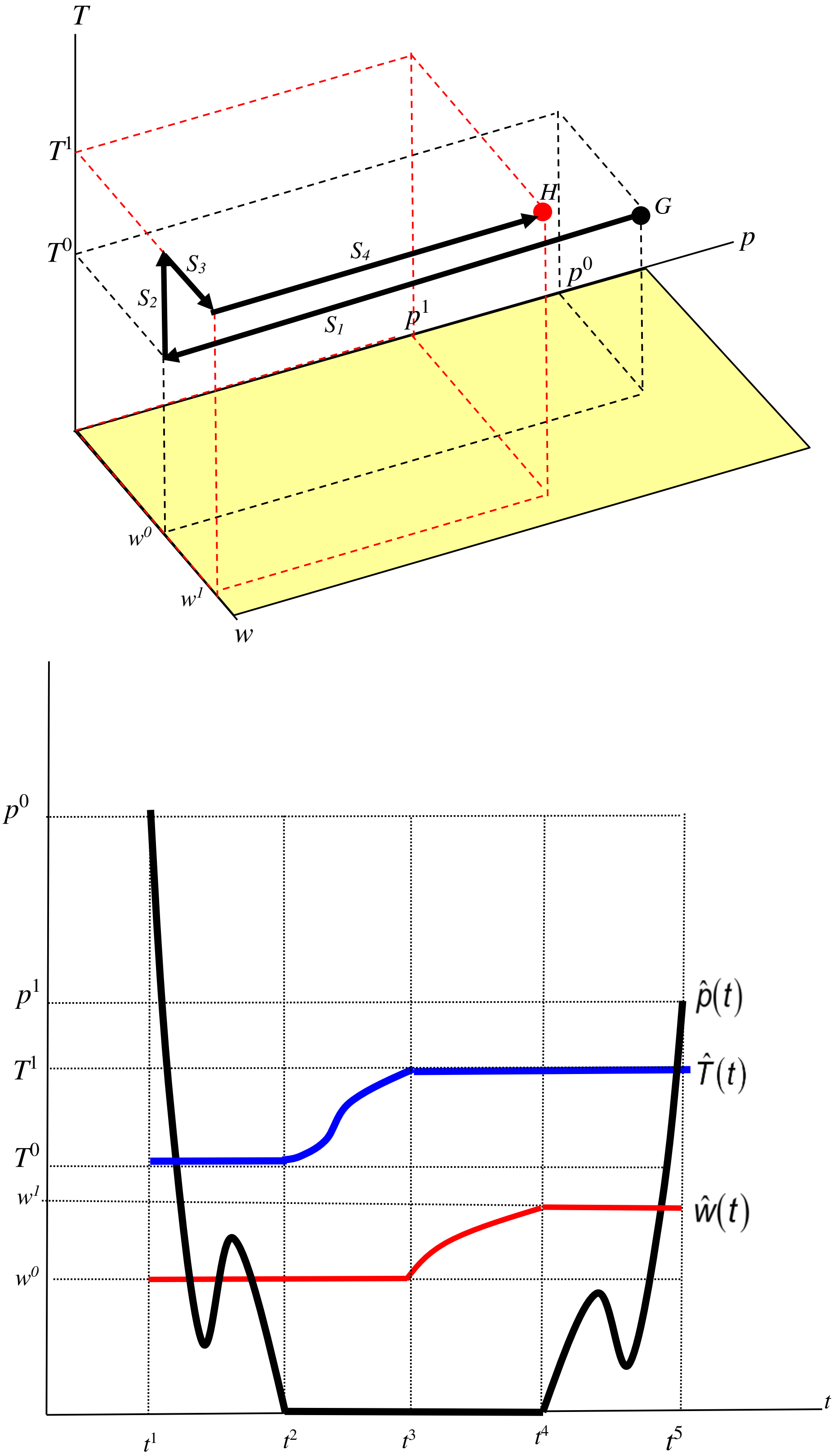

Figure 1. A shutdown path of integration

The result is that we can measure ΔΠ, which is area $A - B$ in figure 2. (See Bullock and Minot (2006) for a fuller discussion of the shutdown price approach, though in the context of consumer theory.).

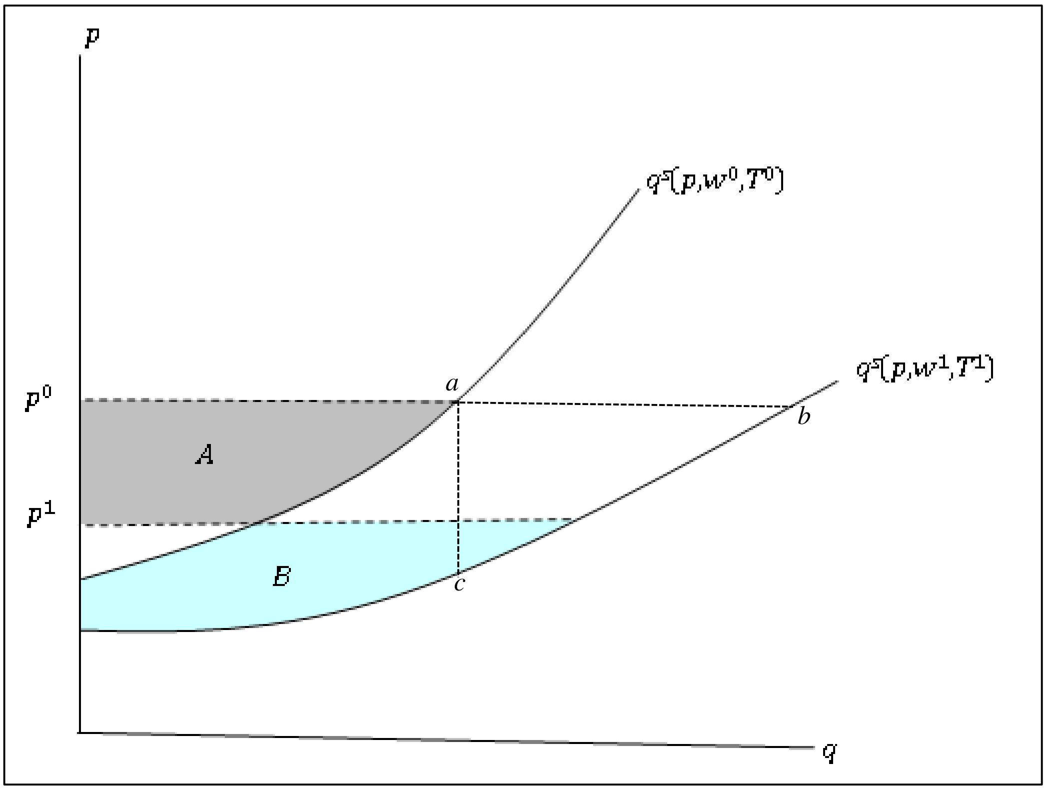

Figure 2. $B - A$ is the shutdown-price measure of producer welfare change when technology and prices all change.

Applying the shutdown price method to the Greek cotton yarn market, we can obtain a producer welfare change measure for the concurrent changes in prices of yarn, the labor wage, and advances in technology with the following integral:

$$(3)\quad \Delta\Pi = \int_{p_y^0}^{0} q_y^s\left(p_y, w_l^0, T^0\right) dp_y + \int_{0}^{p_y^1} q_y^s\left(p_y, w_l^1, T^1\right) dp_y \ ,$$

where $T^0 = T^{i-1}$ and $T^1 = T^i$. The single-market approach requires quantity data from the output (yarn) market only.

Using figure 3, the welfare effect from the single-market analysis is equal to -(A+B+C+K1+K2+M+O1+O2+O3) + (O1+O2+K1) = -(A+B+C+M+K2+O3). The welfare change estimate requires the use of the areas M, K2 and O3, which are usually out of the range of observed price changes. Consequently, the single market approach requires estimation of the area under the supply curve for which researchers usually do not have any information for (See Just *et. al.* 2004, chapter 9, for a thorough theoretical presentation, Vestergaard, 1999, for an application using the single-market approach). Using the single-market approach as we move away from the mean value of observed price changes, the confidence interval for the predicted values of quantities supplied increases, welfare results are less accurate and should be interpreted with caution (Just *et. al.* 1982; 2004)[6].

[6] A formal empirical comparison of the single and the multi-market approaches to welfare change estimation was presented by Dadakas and Katranidis (2008) (without however including technology in the model). Using bootstrap analysis, the researchers found that the welfare estimates from the single-market approach had significantly higher standard errors than those obtained from the sequential approach, thus verifying the theoretical conclusion presented by Just *et. al.* (1982; 2004). Simplification of the research process through the use of the single-market approach yielded less accurate results for the price induced welfare changes.

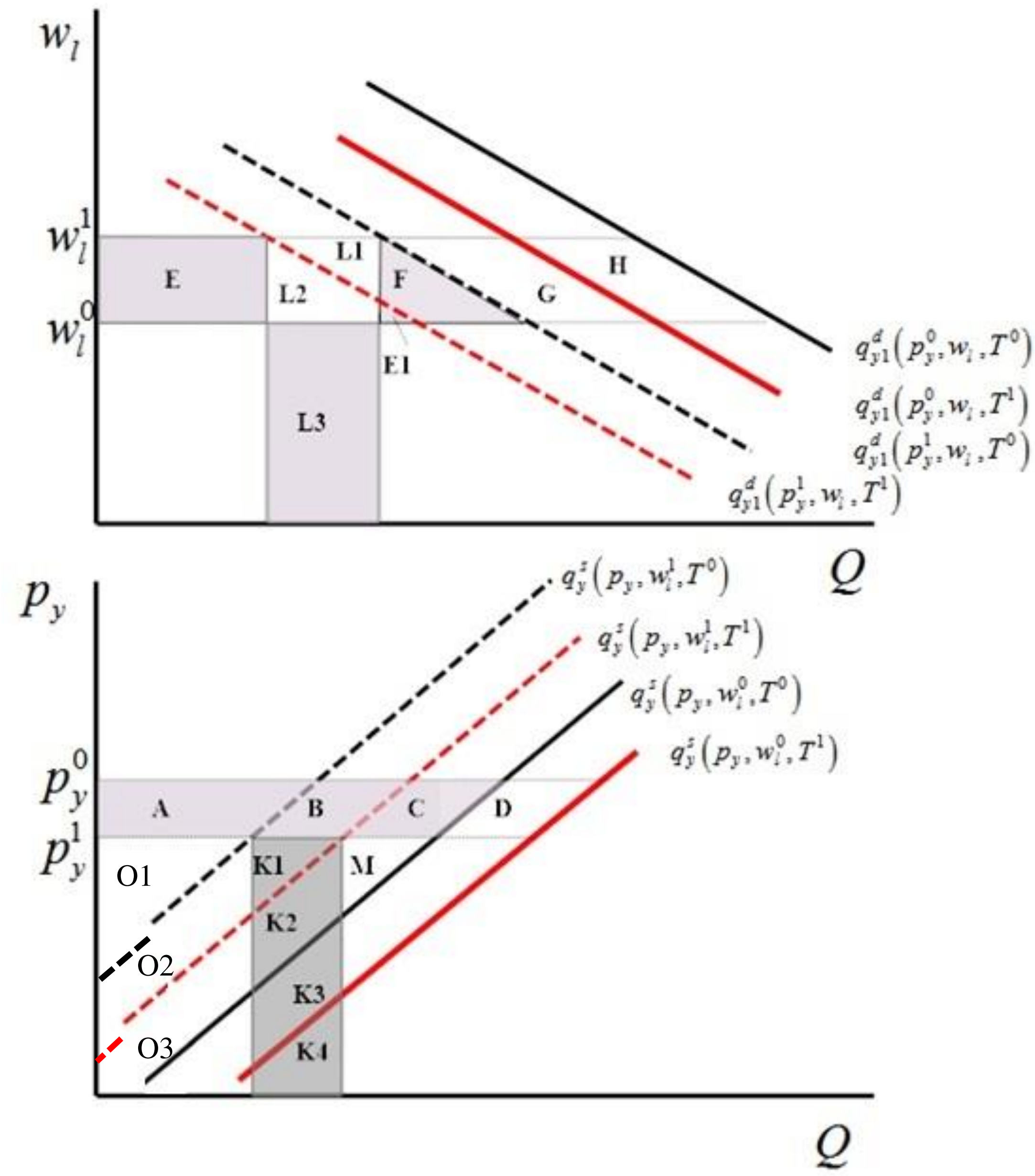

Figure 3. Welfare measures in (quantity, price)-space

An advantage of the single-supply-equation approach is that it can be more easily used to model dynamics, expectations, and risk than can the dual approach. As Alston, Norton and Pardey (1998, p. 113) write, "The key issues in supply-response analysis were identified sixty years ago … as being how to deal with expectations and dynamics; these issues continue to be difficult. The virtue of the single-equation models is that they allow considerable flexibility in the treatment of these topics." In addition, the single equation approach allows for easier incorporation of "expert" advice about the nature of the cost and supply changes brought about by the technological change. In this vein, Alston, Norton, and Pardey (1998, p. 505) write, "There is little point in proceeding with an econometric analysis unless 25 to 30 years of data are available on quantities (and, perhaps, also prices of outputs and inputs, along with data on research and extension expenditures going back a further 20 years or so… .) When adequate time-series data are not available, an economic surplus approach can be used that relies on experimental data and the opinions of scientist and extension workers to estimate the per unit cost changes (or yield improvements) … ." Just has made similar points: "If models of excessive generality are used to analyze production problems, then the ability to communicate about them is reduced. Communication becomes difficult between economists and non-economist providers of information as inputs to economic analysis" (Just 2000, p. 151). "This cuts communication between empirical production economists and the very disciplines that have scientific information that should be incorporated into production studies" (Just 2003, p. 149).

A key piece of information needed to use the shutdown price approach to measure producer welfare change is the size of the shift (either horizontal or vertical) in the supply curve due to the technology change. This shift is called the "*k*-shift" in much of the literature, including in Alston, Norton, and Pardey (1998). The horizontal *k*-shift is distance *ab* in figure 2. The vertical *k*-shift is area *ac*. Often, economists seek the expertise of non-economist scientists for information about the size of the *k*-shift.

3.2.3 A Sequential Approach

To overcome some of the problems presented in the single-market approach we next present a sequential approach towards the estimation of the welfare changes. Because the line integral in (2) is path independent, we can choose a convenient path that allows us to easily convert the line integral into the sum of four definite integrals. This is a path that sequentially changes the variables one at a time from their initial levels to their subsequent levels. The order in which we change the variables of integration is arbitrary. We choose to change p_y from p_y^0 to p_y^1, holding the other variables constant at their initial levels, then to change p_c from p_c^0 to p_c^1, holding p_y at its subsequent level and w_l and T and their initial levels, then to change w holding p_y and p_c at their subsequent levels and T at its initial level, then finally to change T holding the other variables at their subsequent levels. We illustrate this path of integration in figure 4, where we do not feature p_c because we are limited to three dimensions in the diagram, and also because, as is to be explained, p_c does not change in our empirical analysis.

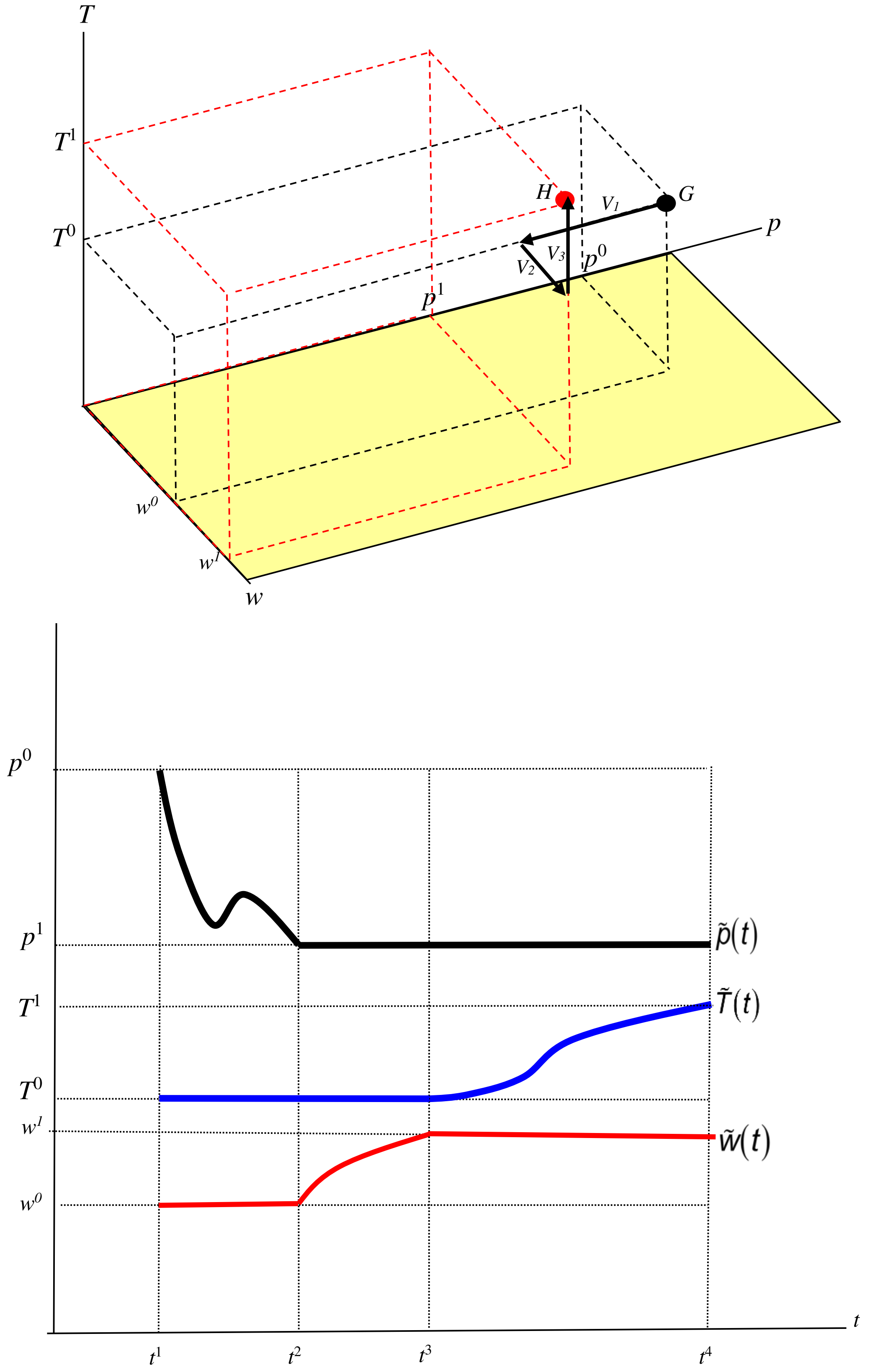

Figure 4. A sequential path of integration

Using definitions in Kaplan (p. 275), the line integral over the sequential path chosen can be converted into the sum of four "sequential" definite integrals shown in equation (4).

$$(4)\ \ \Delta\Pi = \int_{p_y^0}^{p_y^1} \frac{\partial \Pi}{\partial p_y}\left(p_y, p_c^0, w_l^0, T^{i-1}\right) dp_y + \int_{p_c^0}^{p_c^1} \frac{\partial \Pi}{\partial p_c}\left(p_y^1, p_c, w_l^0, T^{i-1}\right) dp_c +$$

$$\int_{w_l^0}^{w_l^1} \frac{\partial \Pi}{\partial w_l}\ p_y^1, p_c^1, w_l, T^{i-1}\ dw_{y1} + \int_{T^{i-1}}^{T^i} \frac{\partial \Pi}{\partial T}\ p_y^1, p_c^1, w_l^1, T\ dT$$

The second integral in (4) is equal to zero as initial prices and final prices of cotton lint are equal. Since there is no intervention in the cotton lint market domestic prices equal world prices and there is no price-induced welfare effect to producers[7]. The remaining terms, combined with the results from Hotelling's Lemma and the envelope theorem, provide us with a measure of the welfare change for producers of yarn:

$$(5)\ \ \Delta\Pi = \int_{p_y^0}^{p_y^1} q_y^s\left(p_y, p_c^0, w_l^0, T^{i-1}\right) dp_y - \int_{w_l^1}^{w_l^1} q_l^d\left(p_y^1, p_c^1, w_l, T^{i-1}\right) dw_l$$

$$+\int_{T^{i-1}}^{T^i} \frac{\partial \Pi}{\partial T}\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right) dT.$$

Because the shutdown-price method usually requires extrapolation of supply curve estimates beyond the data range, it is desirable to seek out another way to deal with the last integral on the right-hand side of (4). To do so, first we refer to the Fundamental Theorem of Calculus, which implies that it can be rewritten:

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[7] Domestic and international prices were equal throughout the period we examine. Minor differences are related to lagged reactions of Greek prices to international trends. Therefore the second integral of equation (2) was approximately equal to zero throughout the period we examine. The lagged reactions are captured in the empirical specification with the inclusion of a dummy variable. However any possible secondary effects from changes in the international demand due to technology improvements in the world markets or changes in the domestic demand would have an effect on our total measure of welfare. This size of this effect is minor as the estimation of a system of equations that includes an equation for cotton-lint shows an insignificant impact. These reasons prompt us to consider the price of cotton lint as constant. .

(6) $$\int_{T^{i-1}}^{T^i} \frac{\partial \Pi}{\partial T}\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right) dT = \Pi\left(p_y^1, p_c^1, w_l^1, T^i\right) - \Pi\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right).$$

The definition of the profit function implies,

(7) $$\Pi\left(p_y^1, p_c^1, w_l^1, T^i\right) - \Pi\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right) =$$

$$\left[p_y^1 q_y^s\left(p_y^1, p_c^1, w_l^1, T^i\right) - w_l^1 q_y^s\left(p_y^1, p_c^1, w_l^1, T^i\right)\right]$$

$$-\left[p_y^1 q_l^d\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right) - w_l^1 q_l^d\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right)\right].$$

Rearranging the right-hand side of (7) and substituting the result into (6) gives us,

(8) $$\int_{T^{i-1}}^{T^i} \frac{\partial \Pi}{\partial T}\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right) dT = p_y^1\left[q_y^s\left(p_y^1, p_c^1, w_l^1, T^i\right) - q_y^s\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right)\right]$$

$$-w_l^1\left[q_l^d\left(p_y^1, p_c^1, w_l^1, T^i\right) - q_l^d\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right)\right].$$

Finally, substituting (8) into (4) gives us,

(9) $$\Delta\Pi = \int_{p_y^0}^{p_y^1} q_y^s\left(p_y, p_c^0, w_l^0, T^{i-1}\right) dp_y - \int_{w_l^1}^{w_l^1} q_l^d\left(p_y^1, p_c^1, w_l, T^{i-1}\right) dw_l$$

$$+p_y^1\left[q_y^s\left(p_y^1, p_c^1, w_l^1, T^i\right) - q_y^s\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right)\right]$$

$$-w_l^1\left[q_l^d\left(p_y^1, p_c^1, w_l^1, T^i\right) - q_l^d\left(p_y^1, p_c^1, w_l^1, T^{i-1}\right)\right].$$

The first integral in (9) is represented by –(A+B+C) using figure 3, measured behind supply curve $q_y^s\left(p_y, w_l^0, T^0\right)$, which is conditioned on initial labor costs and technology. The second integral, which must be subtracted, is (E+L2+L1+E1+F), the area behind the labor demand curve $q_{y1}^d\left(p_y^1, w_l, T^0\right)$, which is conditioned on the final price of yarn and initial technology. The third term on the right-hand side of (8) is rectangle (K1+K2+K3+K4). The fourth term, which must be subtracted, is -

(L1+L2+L3). In sum, the change in producer quasi-rents is represented by -(A+B+C+D) - (E+L1+L2+E1+F) + (K1+K2+K3+K4) - [- (L1+L2+L3)]

With equation (9), we have dealt with the problematical $\frac{\partial \Pi}{\partial T}(\cdot)$ term in (4), and provided an estimable measure for the change in producer's welfare. Unlike dual approaches, our method does not require estimation of the profit or cost function along with the output supply and input demand functions. It also allows use of "expert" advice, because two types of "*k*-shift" are key to its implementation. The first is a *k*-shift in the supply function, appearing in the third term on the right-hand side of (9): $\left[q_y^s \;\; p_y^1, p_c^1, w_l^1, T^i \;\; - q_y^s \;\; p_y^1, p_c^1, w_l^1, T^{i-1} \;\right]$. The second is a *k*-shift in the labor demand function, appearing in the fourth term on the right-hand side of (9): $\left[q_l^d \;\; p_y^1, p_c^1, w_l^1, T^i \;\; - q_l^d \;\; p_y^1, p_c^1, w_l^1, T^{i-1} \;\right]$. Unlike the shutdown price method, our measure does not require integration all the way down the supply curve. This means that in general we are not extrapolating beyond the range of our data, and so our method does not involve the same types of problems with statistical inaccuracy that are encountered when the conventional method is used.

4. Econometric Analysis

To discuss/compare the reliability of the estimated welfare changes implied by equation (9) we also estimate a model that does not incorporate technological advances in the specification. The simplified measure, which uses Just, Hueth, and Schmitz's (2004) sequential integration method, and is discussed in detail in Dadakas and Katranidis (2010) can be estimated through the following equation:

$$(10)\ \ \Delta\Pi = \int_{p_y^0}^{p_y^1} q_y^s\left(p_y, w_l^0\right)dp_y + \int_{w_l^1}^{w_l^1} -q_l^d\left(p_y^1, w_l\right)dw_l.$$

The theoretical conclusion with respect to the statistical reliability of welfare estimates in single market models vs. multi-market models presented in Just, Hueth and Schmitz (1982; 2004) was empirically investigated by Dadakas and Katranidis, (2008)[8]. However, there is no formal comparison of the effect that the inclusion of technological changes have on the statistical reliability/bias of the results within the bounds of our approach, that is the multi-market approach. Other than an initial theoretical discussion presented by Bullock (1993a)[9], we are aware of no study that attempts to estimate the welfare effects of changes in technology and input prices using a sequential approach. For our purposes we compare two models. We use a Multi-Market Technology Inclusive (MMTI) model as the base model (equation (9)) but we also estimate a Multi-Market Technology Exclusive (MMTE) model (equation (10)) so as to compare the two welfare effects and determine whether bias is created due to the omission of technology in the theoretical/empirical development of the model. Deviations of the two measurements are expected if new technologies affect production.

The estimation of the MMTI model requires a supply function for yarn and a derived demand function for labor (equations 11 and 12),

[8] Dadakas and Katranidis (2008) present and compare the statistical properties of the welfare estimates derived from equivalent equations 3 and 10, that is the single-market approach and the multi-market model. Their model however does not include the effects of technology.

[9] Bullock (1993a) examined the welfare effect of technology change when two output markets and hence prices are affected by the change in technology in one of the markets. Our research question involves the estimation of welfare changes brought about by policy induced price changes (one input price and one output price) and concurrent improvements in technology all of which affect the welfare of producers in one output market.

$$(11)\qquad q_y^s = \alpha_0 + \alpha_1 p_{y,t} + \alpha_2 p_{c,t} + \alpha_3 q_{y,t-1}^s + \alpha_4 w_l + a_5 T + a_6 T^2 + a_7 D1 + a_8 D2 + \varepsilon_a$$

$$(12)\qquad q_l^d = \beta_0 + \beta_1 p_{y,t} + \beta_2 p_{c,t} + \beta_3 q_{l,t-1}^d + \beta_4 w_l + \beta_5 T + \beta_6 T^2 + \varepsilon_\beta$$

The effect of technology is represented with variables T and T^2 measured as a simple time trend. p_c^k represents the price of cotton-lint. The first dummy variable (*D1*) assigns the value 1 to the years prior to the signing of the MFA agreement (1974) to capture structural changes in the supply of yarn due to the changing regime. The second dummy (*D2*) assigns a value of 1 to the years immediately prior to the 1987 Uruguay Round of trade negotiations and the 1995 Agreement on Textiles and Clothing (only the years 1986 and 1994 are assigned a value of 1), when domestic intervention prices reached local peaks and global troughs, respectively, also representing structural breaks in the data[10]. In the supply equation, we adopt a partial adjustment framework with lagged supply entering the equation as an explanatory variable, while in the demand equation habitual consumption requires the use of past year's demand as an explanatory variable.

To assure that the profit function is well-defined and the line integral path independent we impose the following symmetry restriction (Young's theorem) ,

$$(13)\quad \frac{\partial q_l^d}{\partial p_y} = -\frac{\partial q_y^s}{\partial w_l}$$

which is equivalent to $\beta_1 = -\alpha_4$ **[11]**. This restriction is necessary in empirical work to assure that the welfare change estimates from all possible paths are equal. The results

[10]During these years the observed shift in trend in prices in the domestic market followed the shift in trend in the international markets with a one year lag. A possible explanation is that expectations and adjustment to trade liberalization, which affected Greece's composition of imports/exports, as well as production levels, had a delayed effect in the domestic market as Greece, historically, enjoyed a very high level of protection offered by the MFA regime.

[11] Had we included in the analysis cotton lint, i.e., if the domestic prices of cotton-lint and the international prices differed we would have to estimate another equation for the derived demand for

are then used in combination with equation (9) to estimate the welfare changes. The welfare effects from additional corner paths were estimated to assure that all estimations were done properly and that equality of the welfare effects estimated from different paths holds. These, however, are not presented in detail.

The MMTE model uses equations (11) and (12) for the econometric estimation together with restriction (13). It does not include the technology variables $\left(T\ ,T^2\right)$. Equation (10) is used for the estimation of the welfare changes.

The data for our statistical analysis came from the Greek Ministry of Agriculture, the World Textile Demand (ICAC, 2003), ICAP, ILO, the Feenstra and Lipsey (2005) database, and the Annual Statistics of the Greek Industry. The CPI index (1987 = 1) was used as the *numéraire* commodity and all measures were transformed to metric. The world prices for labor and the world prices for cotton yarn, i.e. the upper limits of the integrals in equations (9) and (10), are a weighted-average estimate from the eight largest volume-exporting countries in the world. All estimation were made in Greek drachmas and results were converted to US dollars. Our statistical sample included data from 1970 to 2001, a total of 32 observations. Welfare changes were estimated only up to the year 2000 due to data limitations not allowing us to complete world prices of labor and cotton yarn after that year (one of the limits of each integral in equations (9) and (10)).

The next step in the analysis requires we compare the welfare effects from the two models to infer on the bias created by omitting technology in the specification of the model. The point estimates of the annual welfare changes provided by the two models do not allow formal tests for the bias created. We thus need to assign statistical

cotton-lint in our system of equations and the symmetry property would require 6 restrictions instead of 1.

properties to our point estimates and retrieve a mean and a variance for our welfare estimates. We employ non-parametric bootstrap analysis (Efron 1993; Kling and Sexton 1990) and compare the welfare effects from the MMTI and the MMTE models. We estimate the difference in the "*mean welfare change*" obtained from the bootstrap, as follows,

$$\Delta W_{MMTI,MMTE} = \frac{1}{1000}\sum_i \left[\Delta\Pi_{MMTI}\left(a_j, \beta_j\right)\right]^i - \frac{1}{1000}\sum_i \left[\Delta\Pi_{MMTE}\left(a_j, \beta_j\right)\right]^i .$$

Where i is the number of the bootstrap sample estimated and j the coefficient included in the regressions. Hence, we examine whether the size of $\Delta W_{MMTI,MMTE}$ statistically deviates from zero. Significance would indicate that there is bias created by the omission of technology in the estimation of the welfare changes. The expected value of this measure is equal to zero when there are no technological improvements associated with the welfare change.

5. Welfare and Bootstrap Analysis

Regression results are presented with the help of table 1. The MMTI model explains 94.6% of the variability, while the MMTE explains 93% of the variability of the dependent variables. The Durbin-h test was not statistically significant and all the variables carry the expected signs.

Table 1. Regression Results (SUR)

	MMTI		MMTE	
	Supply of Yarn	**Derived Demand for Labor**	**Supply of Yarn**	**Derived Demand for Labor**
Constant	6,316.379 (0.232)	-961.865 -(0.245)	45,765.445 (3.099) ***	2,651.088 (0.796)
T	6,807.657 (2.920) ***	918.165 (2.163) **		
T2	-130.013 -(2.937) ***	-17.841 -(1.955) *		
$Q^{d}_{y1,\,t-1}$		0.619 (5.177) ***		0.786 (9.539) ***
$Q^{s}_{y,\,t-1}$	0.215 (1.312)		0.571 (5.225) ***	
P_c	-0.016 -(0.589)	0.000 (0.053)	-0.027 -(0.887)	-0.002 -(0.376)
P_y	0.050 (1.647) *	0.015 (2.475) ***	0.042 (2.145) **	0.011 (2.086) **
w_l	-0.0152213 (-2.475) ***	-0.010502 -(2.540) ***	-0.011 -(2.086) **	-0.004 -(1.642) *
D1	12,275.540 (2.832) ***			16,058.641 (3.517) ***
D 2	-21,814.533 -(2.954) ***			-24,637.754 -(2.999) ***
Durbin-h	1.136	0.466	-0.03	-0.376
Restriction	-89.25 (-2.04) **		-52.43 (-1.27)	
System $\bar{R}^2$	0.946		0.933	

Note: Values in parenthesis are t-statistics
*** significant at α=0.01, ** α=0.05, * α=0.1

The pattern of welfare changes estimated with equations (9) and (10) shows declining transfers to Greek producers throughout the period 1975-2000 (figure 5). Although the estimated welfare effects barely differ until 1992, thereafter the MMTI model produces substantially lower welfare estimates[12]. An explanation for the deviation in the two welfare measures is that the high costs of labor combined with expectations for decreased product prices, due to the impending 1995 liberalization of

[12] Note that these results do not imply that technology had a negative impact on producers' transfers. The difference in the welfare levels is due to the misspecification of the MMTE model.

trade, led to investments and innovations for new labor saving technologies intended to assist producers to compete in the international markets effectively. Since the MMTE model does not account for these changes it cannot differentiate the pre- and post-1991 welfare results to producers due to changes in technology. Thus the MMTE model overestimates the true welfare effects after 1992. The differences peak after the final signing of the 1995 Agreement on Textiles and Clothing (ATC), when quotas were gradually eliminated and prices of cotton yarn products decreased.

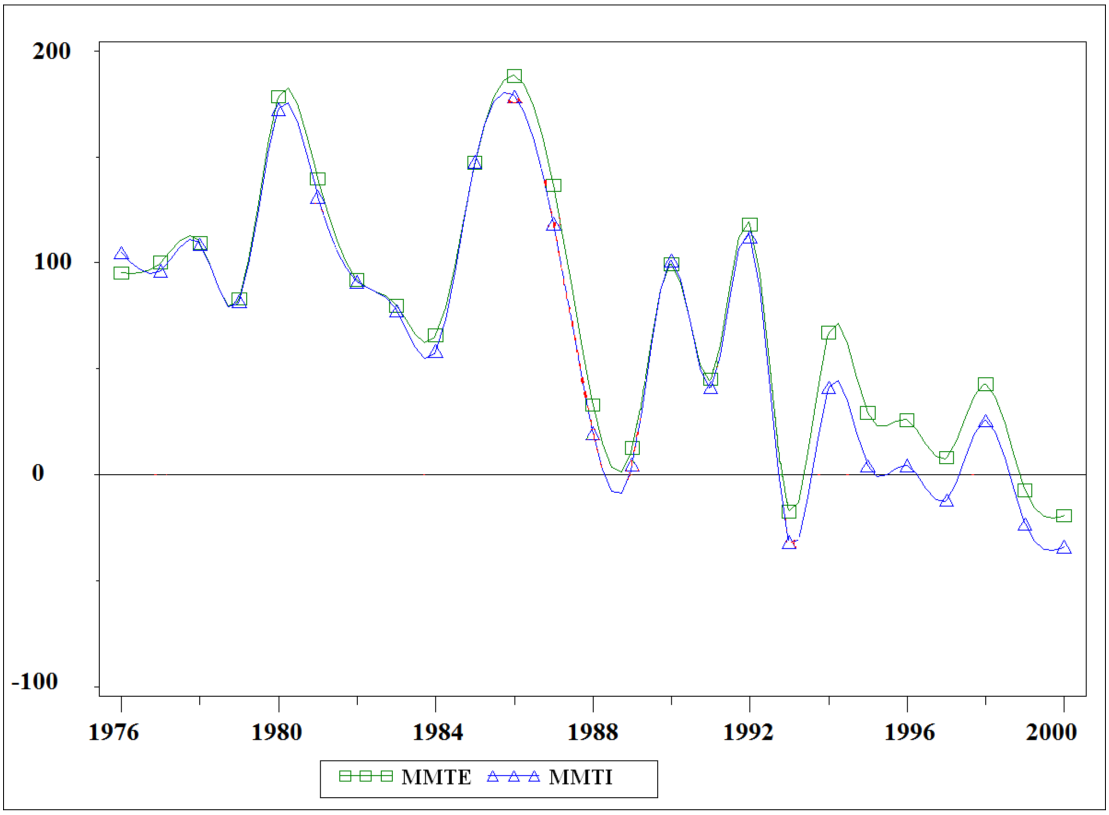

Figure 5. Estimated welfare effects on producers of cotton yarn

Using the shift method (Noreen, 1989) to obtain the bootstrapped welfare estimates of the MMTI and the MMTE models, we examined the differences in the two welfare measures. Figure 6 plots the α-levels for which the differences in the MMTI and the MMTE welfare estimates are statistically significant.

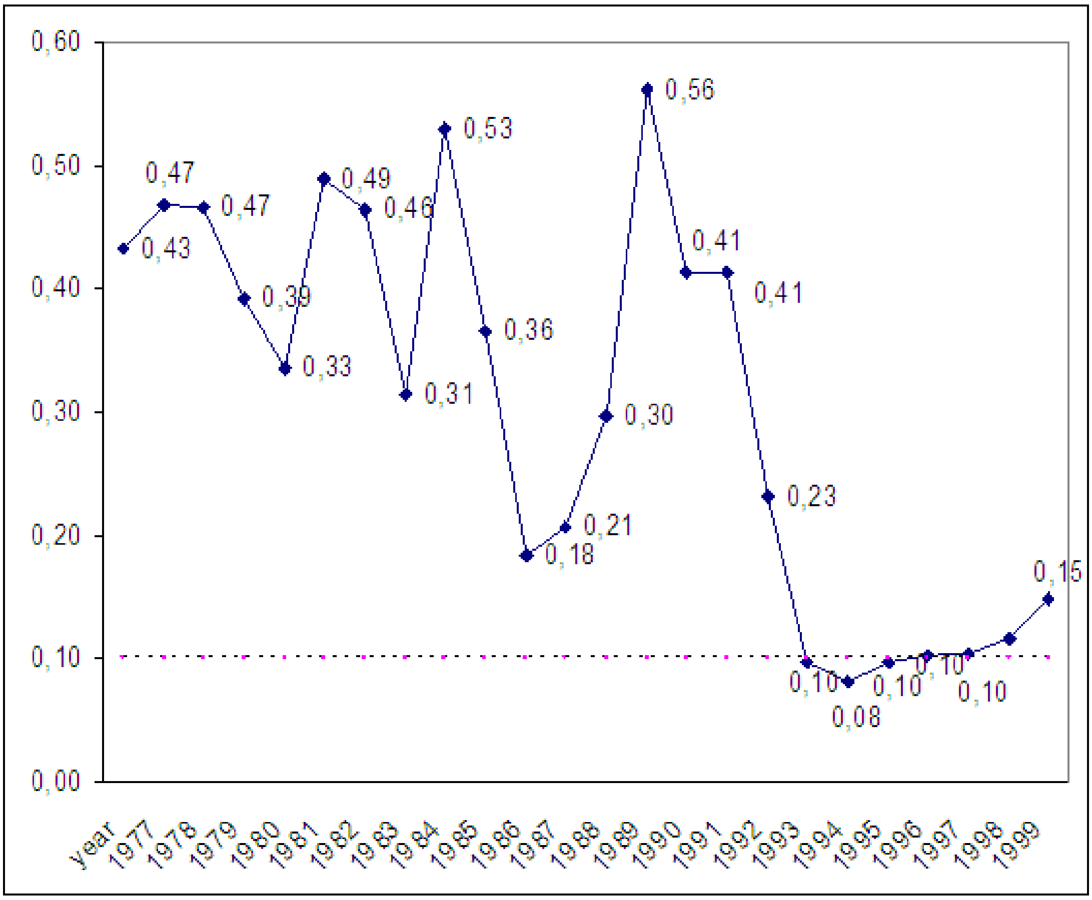

Figure 6. Shift method results

The analysis suggests that results do not differ significantly for most of the years we study. Statistically significant differences are observed for the years 1994-1999, consistent with the observations made with the help of figure 4. We believe that the non-significant differences during 1999-2000 are related to China's upcoming entry to the WTO that resulted in an increased world demand for cotton products. During this period, innovations and the adoption of new technologies resulted in bias in the welfare effects estimated from the MMTE model. Such differences are expected to be stronger for countries such as the US and the EU where the majority of R&D in Textiles and Clothing is conducted. Greece's benefit from new technologies originates mainly from diffusion and not from R&D per se.

6. Conclusions and Applications

Various approaches are available in the literature to estimate the impact of technology changes on the welfare of producers. When these changes are combined with policy-induced price-changes in vertically or horizontally linked markets we need to examine all changes at the same time and take into account the complexity of price relations between markets. Unfortunately, the commonly used single-market approach and dual approaches cannot be considered as a panacea for all economic problems. The limitations presented by the statistical reliability of the welfare results in single-market approaches (Just, Hueth and Schmitz 1982;2004; Dadakas and Katranidis, 2008) and the struggle of dual approaches with dynamics and expectations (Alston, Norton, and Pardey, 1998) prompt us to adapt our approach so that it can deal with the intricacies of the markets in this research. We provided an extended application of a model first presented by Bullock (1993a). The model allowed us to estimate the price-induced welfare changes in a multi-market setting inclusive of the effects of technology. Our main conclusion suggests that when new technologies affect production, the model used to estimate the welfare changes must account for the effects of technology to avoid biasing the results.

Our model can be applied to welfare change estimation problems, in either vertically or horizontally linked markets, when price-policy affects concurrently two or more prices and at the same time technology affects production. Our model provides researchers with a viable and valuable alternative in many situations, such as estimating welfare changes when economic research is related to agricultural and industrial economics where linked markets, multiple price changes and technology improvements are all encountered under one roof.

Current research is directed towards a simulated formal comparison of the welfare effects estimated via the multi-market sequential approach we presented in this article and the dual approaches. Since in many cases researchers will have the option to use either the multi-market approach or a profit function our next research endeavors are directed to the statistical properties of the welfare effects from each method to examine which method provides more efficient/reliable estimates. Another line of research will concentrate on the costs of equipment, machinery and training associated with the implementation of new technologies, investment costs as well as welfare analysis involving non-price factors as presented by Just et. al. (2004).

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