A Welfare Analysis of Biological Technical Change under Different Supply Shift Assumptions: The Case of Cocoa in Malaysia

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Emerging modern biotechnological improvements will make possible the cultivation of crops with higher yields, while enhanced resistance to pests and diseases will facilitate a reduction in the use of pesticides. In this article, the welfare effects of a regional technical change in relation to a perennial crop are measured. Dynamic aspects of supply responses to prices as well as to changes in technology are addressed when the effects of biological lag and the variation of asset productivity are taken into consideration. The effects of the adoption of improved cultivars are assessed for both a parallel and a conservative, pivotal shift in the supply curve. The theoretical model is implemented for cocoa in Malaysia as a large producer country on the one hand and all other countries as an aggregate on the other. Relatively small price and quantity effects result from the adoption of new cultivars. Although the magnitude of the effects on producer benefits and total benefits in Malaysia depend crucially on the type of supply shift assumed, significant benefits occur for Malaysian producers. Consumers' gains in the ROW are approximately offset by producers' losses in the ROW, suggesting that a considerable share of the gains would benefit consumers in economically well-developed northern hemisphere countries at the expense of producers who do not immediately adopt improved cultivars.

Les améliorations biotechnologies émergentes rendent possible la culture de variétés à plus haut rendement, munies d'une résistance élevée contre les maladies et ravageurs permettant la réduction des applications de produits phytosanitaires. Dans cette article, les effets sociaux bénéfiques d'un progrès technologique régional pour les cultures pérennes sont mesurés. Les aspects dynamiques de la réaction de l'offre à des changements de prix et de technologie sont étudiés en considération des effets du retardement biologique et d'une variation du capital fixe. Les effets de l'adoption de cultures améliorées sont étudiés lorsqu'un déplacement parallèle et pivoté de la fonction de l'offre est admis. Le modèle théorique est réalisé pour le cacao en Malaisie, avec d'un côté la Malaisie en tant que grand pays producteur et le reste du monde de l'autre côté. Les résultats montrent que les effets de l'adoption de cultures améliorées sur les prix et quantités sont relativement modestes. Bien que les effets sociaux bénéfiques totaux et notamment ceux pour les producteurs en Malaisie dépendent essentiellement du type de déplacement de la fonction de l'offre, des gains importants sont réalisés par les producteurs en Malaisie. Les gains des consommateurs du reste du monde sont à peu près compensés par les pertes des producteurs dans le reste du monde ce qui suggère qu'une partie considérable des gains va en faveur des consommateurs dans les pays très développés de l'hémisphère nord au dépens des producteurs n'adoptant pas immédiatement les cultures améliorées.

INTRODUCTION

The greatest impact of agricultural biotechnology will be felt in production (Buckwell and Moxey 1990). In this article, biotechnological progress is interpreted in a comprehensive sense according to Bull, Holt and Lily (1982, 21) including "the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services." As Gotsch (1997) shows in a recent survey for cocoa, considerable reduction in yield losses caused by several pathogens and pests can be achieved combining traditional resistance breeding with modern biotechnical tools such as molecular markers for the genetic characterization of resistance characteristics of cocoa germplasm and for the genetic characterization of cocoa pathogens. The use of genetic engineering for the improvement of cocoa disease resistance is of secondary importance. A technical change of this nature is likely to be specific to a particular region, since the pests themselves are regionally specific. In this article, the welfare effects of such a regional technical change in relation to a perennial crop are assessed. These effects differ for consumers and producers, as well as for the adopting country and the Rest of the World (ROW).

Alston, Norton and Pardey (1995) describe a comparative-static model for the quantification of welfare effects resulting from research-induced supply shifts of competitive industries. In this paper, Alston, Norton, and Pardey's (1995) framework is applied to the quantification of welfare effects when the commodity under consideration is a perennial crop. Significant perennial crop features that require modification of the existing framework include incorporating

- dynamic supply response to prices
- biological lags in production
- vintage effects to account for variation in the productivity of the plant/tree by age.

In the application to the cocoa market, the framework has been adjusted to account for the time path after initial adoption, taking into consideration the long-term supply response for a time horizon of 30 years, which corresponds approximately to the expected life of a cocoa tree.

Welfare effects on the cocoa market are calculated assuming both parallel and pivotal shifts in supply. While the results for the parallel shift may be regarded as the "expected" effects, conservative estimates are provided for the case of a pivotal shift. Unfortunately, economic theory is not informative about either the functional form of supply and demand or the type of the research-induced supply shift. One would need to examine the characteristics of individual firms that affect marginal costs and technology adoption in order to predict which types of firm would benefit from a particular new technology. Furthermore, it is impossible to get statistical results that can be extrapolated to the price or quantity axes (i.e., the full length of the supply function). Assumptions about the nature of the research-induced supply shift are unavoidable.

The theoretical model is implemented for the *ex ante* assessment of the welfare effects for cocoa as a perennial tree crop in the case of two countries, one of which is a producer that adopts cocoa cultivars with an improved resistance to insects, pests and diseases, and another country called the ROW as an aggregate, which is not in a position to adopt the same technology. An important result of the empirical analysis for Malaysia is the relatively small price and quantity effects resulting from the adoption of new cultivars. Benefits to producers and consumers are generally deferred until many years later because of long lags between invest-

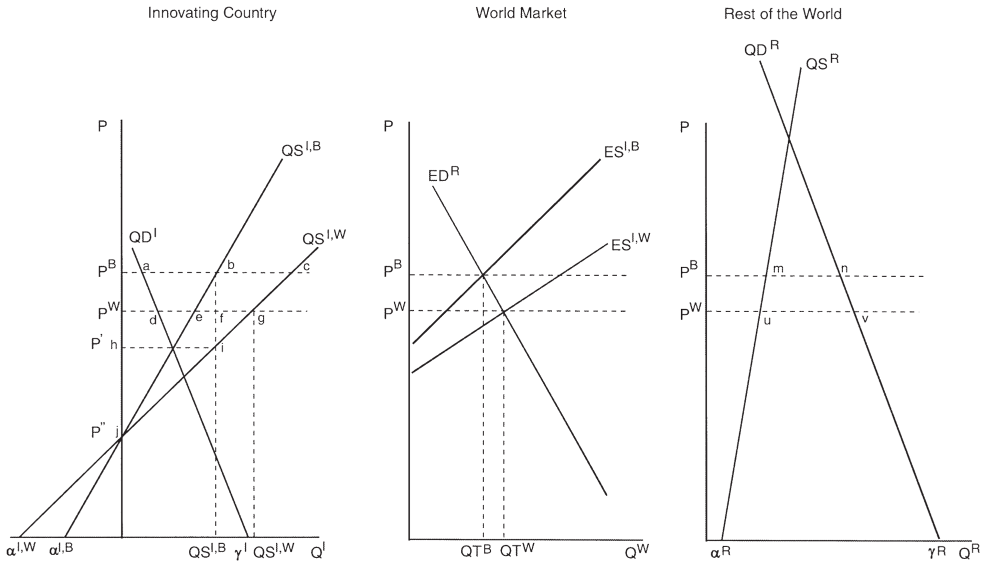

Figure 1. Welfare effects in the case of a large innovating exporter due to the adoption of improved technology

ment and resulting effects on market supply. Nevertheless, Malaysian producers can be expected to gain considerably by the thirtieth year, with positive benefits occurring only five years after the initial investment in the research. Consumers can be expected to benefit in all countries while producers in the Rest of the World realize considerable losses from the adoption of improved planting material in Malaysia. Overall, consumers gain the largest share of the increase in welfare benefits, mainly at the expense of producers in the ROW.

ECONOMIC SURPLUS MEASUREMENT OF RESEARCH BENEFITS

Figure 1 is a conventional, comparative-static, partial equilibrium model of supply and demand for a two-country situation with a large innovating export country whose excess supply is imported by the ROW. Changes in supply of the large exporter affect the world market price. Furthermore, linear supply-and-demand functions and a pivotal shift of the supply function due to the adoption of the improved technology are assumed.

The supply function before the new technology is adopted is denoted by $QS^{I,B}$ for the innovating country in the left-hand diagram, and by QS^{R} for the ROW in the right-hand diagram. QD^{I} in the left-hand diagram is the demand in the innovating country, and QD^{R} in the right-hand diagram the demand of the ROW. The excess export supply in the innovating country before the adoption of the new technology is shown as $ES^{I,B}$ in the middle diagram, given by the horizontal difference between $QS^{I,B}$ and QD^{I}. The excess import demand from the ROW is shown as ED^{R} in the middle diagram, given by the horizontal difference between demand QD^{R} and supply QS^{R} in the ROW. International market equilibrium is established by the intersection of ED^{R} and $ES^{I,B}$ at a price P^{B}. At that price, QT^{B} is exported by the innovating country (*ab* in the left-hand diagram) and imported by the ROW (*mn* in the right-hand diagram).

The adoption of the new technology in the innovating country causes a clockwise rotation of the domestic supply function by *bi* in its intercept with the price axis from $QS^{I,B}$ to $QS^{I,W}$, and in consequence, the excess supply shifts from $ES^{I,B}$ to $ES^{I,W}$. The new lower equilibrium price is P^W. The corresponding traded quantity is QT^W (*dg* exported by the innovating country equaling *uv* imported by the ROW).

Consumers in both countries gain. Consumer benefits in the country adopting the new technology (measured by the change in consumer surplus) are given by the area $P^B adP^W$ in the left-hand diagram. Consumer benefits in the ROW amount to $P^B nvP^W$ in the right-hand diagram. Producers in the innovating country benefit. Their surplus gain is measured as the difference between the areas of the triangles $P^W gj$ and $P^B bj$. Producers' losses in the ROW correspond to the area $P^b muP^W$.

Determinants of the Size and Distribution of Benefits

In order to measure changes in producer and consumer surplus associated with the adoption of an innovation, it is necessary to define explicit mathematical functions representing supply-and-demand equations and the supply shift. Assumptions on functional forms, instead of relying on data-based econometrically estimated relationships, are necessary because the accurate measurement of demand-and-supply curves along their entire length is very difficult. Some aspects of the measurements are sensitive to assumptions about:

- supply-and-demand elasticities
- functional forms of supply and demand
- the nature of the research-induced supply shift.

The use of linear supply-and-demand functions makes it easy to calculate the geometric areas of surplus changes using simple algebra. With such curves, the elasticities change as quantity changes along the curve — and one must be explicit about where the assumed elasticities apply — before or after the innovation-induced market displacement. Alston and Wohlgenant (1990) demonstrate that the calculation of welfare effects based on linear supply-and-demand functions and a parallel innovation-induced supply shift cause less than 10% deviation from models using supply-and-demand functions with constant elasticities (or any functional form inbetween). From this, they conclude that a model assuming linear functions of supply and demand and a parallel shift of the supply function due to the adoption of improved technology provides a good approximation for the measurement of total benefits and their distribution among producers and consumers. In a recent paper, Zhao, Mullen and Griffith (1997) derive analytical expressions for the magnitude of the errors from assuming linear functional forms and parallel supply shifts. Their results provide further support for Alston and Wohlgenant's conclusion that a model with linear functional forms provides a close approximation to measurement of welfare changes for small parallel supply shifts.

There has been a great deal of discussion in the literature about the effects of different types of research-induced supply shifts on the size and distribution of research benefits. The matter has never been resolved satisfactorily (see Lindner and Jarrett 1978, 1980; Rose 1980; Wise and Fell 1980). However, this choice is crucially important in the analysis. For example, given a linear supply function, the total benefits from a parallel shift are almost twice the size of the total benefits from a pivotal shift of equal size at the pre-research equilibrium. Furthermore, when the supply shift is parallel, producers always benefit from research unless supply is perfectly elastic or demand is perfectly inelastic, and even in these extreme cases, producers are no worse off as a result of research. On the other hand, with a pivotal shift, producers benefit only when demand is elastic and necessarily lose when demand is inelastic (see, for instance, Lindner and Jarrett 1978). A parallel shift implies that the change in average costs equals the change in marginal costs at every point along the curve. Often, reasonable estimates of the change in average cost at the current equilibrium are available. In a recent paper, Wohlgenant (1997) shows that if firms differ in one respect or another, aggregation over firms can affect the nature of the supply shift. The presence of inframarginal (versus marginal) firms complicates the analysis relative to the case of identical, marginal firms. With inframarginal firms, it is necessary to know how both production costs and rents (or quasi-rents) are affected by research in order to quantify the effect on firms' supply response. One implication of this finding is that for the calculation of aggregate producer surpluses neither a strictly parallel supply shifts nor a strictly pivotal shift should be assumed. A realistic strategy is to follow the suggestion made by Alston, Norton and Pardey (1995) to assume that the supply shift is parallel and use a pivotal shift in order to generate conservative estimates of total economic benefits. For this reason, the theoretical model is developed for both a parallel and a pivotal shift of the supply function in this paper.

CALCULATION OF THE RESEARCH-INDUCED SUPPLY SHIFT FOR PERENNIAL CROPS

In the case of cocoa, which is used as an example of a perennial crop in our model, a specialist survey conducted by Gotsch (1997) demonstrates that new planting material with improved resistance to insects, pests and diseases is expected to become available to producers about 25 years after making an investment in research and development. Cocoa biotechnology experts and breeders agree that such a long research lag must be assumed due to the biological and technological constraints inherent in cocoa breeding and propagation because gestation lags of three to five years and long reproductive cycles reduce the speed of the breeding process and of field testing of improved planting material. Once the research lag has expired, research benefits are calculated in the model for a period of 30 years, corresponding approximately to the expected life of a cocoa tree. Research costs for the development of improved cultivars were not taken into account since no precise information on research expenditure for cocoa in Malaysia was available. We estimate that if research costs were taken into account, the resulting reduction in the net present value (NPV) of total welfare gains created for Malaysia by this technology would amount to less than 5%.

Formulas referring to the situation before new planting material is available are indicated by superscript *B*. Formulas referring to new planting material are indicated by superscript *W*. Because new planting material is not fully adopted from the beginning of its availability, cocoa production during this latter period can occur with old planting material, referred to as superscript *O*, or with new planting material, referred to as superscript *N*.

Research-induced Supply Shift

The supply curve shifts in response to the adoption of a new crop that has both higher yields per hectare and lower costs per hectare. The relative change in yields is given by EY_t and the relative change in costs per hectare is given by EAC_t. Dividing EY_t by the supply elasticity ε converts EY_t into a relative gross reduction in marginal cost per tonne of output with new planting material, EMC_t.[1] Dividing EAC_t by $(1 + EY_t)$ yields the relative change in production costs per tonne of output with new planting material, ECI_t. Subtracting ECI_t from EMC_t yields the relative net cost change per tonne of output in year t with new planting material, ENC_t. Multiplying ENC_t by the initial producer price, PP^B_0, yields the supply shift down by an amount per unit induced by the adoption of the new planting material, k_t.

Calculation of the Variables Defining k_t

According to Akiyama and Trivedi (1987), long-run responses for perennial crops in the form of changes in capacity require an intrinsically dynamic supply theory, which is embodied in the so-called vintage production approach. For a period of years, a so-called vintage matrix indicates the age distribution of the area under cocoa according to the age of the trees. The rows of the matrix represent the tree age i starting with year $i = 0$ (year in which the trees are planted) and ending with age $i = l$. The columns represent years. The values in each cell give the area under cocoa per tree age and year. The discarding of cocoa is taken into account in the vintage matrix through a discarding fraction, which is related to the age of the tree. The fraction *disc(i)* of the remaining acreage of age i being discarded is represented by:

$$disc_i = \frac{1 - e^{\frac{-1}{r\mu}}}{1 + e^{\frac{\mu - i}{r\mu}}}$$

where μ is the age at which discarding reaches half the maximum share, and r represents the speed by which discarding increases as trees grow older (Burger and Smit 1997a). In the model presented here, the parameters of the discarding function remain constant over time. In reality, they may vary over time. But, since no time-series data on areas of various age classes discarded are available, such changes in the parameters of the discarding function cannot be estimated empirically.

For the calculation of the proportionate yield change resulting from the adoption of the new cultivar, EY_t, and the proportionate change in production cost per hectare in year t at that specific adoption level, EAC_t, the total area of old and new planting material in the year t must be calculated for each tree age i and each year t.

The area newly planted with old planting material in year t is called $A^B_{i,t}$. It is determined endogenously with the help of the investment decision model (see following subsection). The area cultivated with old planting material of tree age i ($1 < i < l$) in year t amounts to:

$$A^B_{i,t} = A^B_{i-1,t-1} - A^B_{i-1,t-1} disc^B_i \tag{1}$$

where $A^B_{i-1,t-1}$ is the area cultivated with trees of age $i - 1$ in year $t - 1$, and ($A^B_{i-1,t-1}\ disc^B_i$) is the area of trees of age $i - 1$ discarded in year t.

The total area cultivated in year t before new planting material is available amounts to:

$$TA^B_t = \sum_{i=1}^{l} A^B_{i,t} \tag{2}$$

Even after new planting material has become available, old planting material still remains in production for a number of years. The total area cultivated in year t with trees originating from old planting material in spite of the fact that new planting material is available amounts to:

$$TA_t^{W,O} = \sum_{i=1}^{l} A_{i,t}^{W,O} \tag{3}$$

The total area cultivated with trees of new planting material in year t is:

$$TA_t^{W,N} = \sum_{i=1}^{l} A_{i,t}^{W,N} \tag{4}$$

The total area cultivated in year t when new planting material is available amounts to:

$$TA_t^{W} = TA_t^{W,O} + TA_t^{W,N} \tag{5}$$

The next step is to calculate the relative yield change per hectare for each year t when new planting material is adopted. This is:

$$EY_t = \left(Y_t^{W} - Y_t^{B}\right) / Y_t^{B} \qquad 6)$$

where Y_t^W is the average yield per hectare in year t when new planting material is available and Y_t^B is the average yield per hectare in year t when only old planting material is available. These average yields depend on the yield profile of old and new planting material and on the fractions of various tree-age classes in the total area cultivated:

$$Y_t^{B} = NP_t^{B} / TA_t^{B} \tag{7}$$

NP_t^B is the total normal production of trees originating from old technology:

$$NP_t^{B} = \sum_{i=1}^{l} \left(A_{i,t}^{B} NY_i^{B}\right) \tag{8}$$

NY_i^B is the so-called normal yield for the old planting material. Normal yields, normal production and average yields per hectare do not necessarily correspond to actual yields, actual supply and actual yields per hectare in the corresponding year. The variables defined here represent potential values assuming some average national standard husbandry, whereas actual yields, actual supply and actual yields per hectare are determined by (real) producer prices and may deviate considerably from normal values as producer prices influence production intensity. The effect of a change in prices on welfare benefits is taken into account by the movement along the supply function.

The computation of the average yield per hectare with new planting material, Y_t^W, follows the same lines as for old planting material:

$$Y_t^W = NP_t^W / TA_t^W \tag{9}$$

Total production costs per hectare can be calculated for each tree age i in year t. $TC_{i,t}^B$ is the total production cost per hectare of i-year-old trees originating from old planting material in year t. $TC_{i,t}^N$ corresponds to total production costs per hectare of i-year-old trees originating from new planting material in year t.

Average production costs per hectare in year t are calculated for each technology as:

$$AC_t^B = \sum_{i=1}^{I} \left(A_{i,t}^B TC_{i,t}^B \right) / TA_t^B \tag{10}$$

$$AC_t^W = \left[\sum_{i=1}^{I} \left(A_{i,t}^{W,O} TC_{i,t}^B \right) + \sum_{i=1}^{I} \left(A_{i,t}^{W,N} TC_{i,t}^N \right) \right] / TA_t^W \tag{11}$$

As a result of the adoption of new planting material, the relative change in production costs per hectare in year t amounts to:

$$EAC_t = \left(AC_t^W - AC_t^B \right) / AC_t^B \tag{12}$$

In the aggregate, farmers will face temporarily higher costs caused by the additional new planting and the change in costs associated with the new technology. These changes will induce a shift in their aggregate supply function. Relative changes in average production costs per hectare are negative in early years of the simulation period because production costs per hectare of new cultivars are lower for trees up to four years compared with production costs of old cultivars. However, production costs for old varieties of trees over four years of age are lower than those of new cultivars. These higher production costs per hectare for older trees stemming from improved cultivars mean that changes in average production costs per hectare become positive only from year 7 of the simulation period.

The Investment Decision Model

Burger and Smit (1997b) provide an overview of the central issues in the theory of replanting perennial crops. A main finding is that, for most authors, a major constituent in the decision procedure on new planting is the NPV of the expected future net income stream from an investment. The NPV, with a suitable discount factor r, indicates the present value of an investment. For the results presented here, a discount rate of 4% is assumed. Sensitivity analyses with 6% and 8% discount rate are accomplished by Gotsch (1999). Benefits and costs are linked to the age of the trees. To start with, there are heavy costs, which are then followed by annual benefits that continue over the full life of the trees once they have reached maturity. The returns on new plantings are calculated, including all the costs that are specific to the ages. These include establishment costs, maintenance costs during and after immaturity, benefits from intercropping during the immaturity period, benefits from production and the labor costs involved in harvesting.

Burger and Smit (1997b) stress the importance of the time-frame taken into consideration in the analysis. They propose that not only one cycle of trees of age i ($i = 1, \ldots, I$) should be considered for the calculation of the NPV but an everlasting series of cycles, each lasting

I years. If the decision maker considers growing the crop, it will be replanted at the age that is seen to be the most advantageous, and this continues in all future cycles. $INC_{i,t}$ is defined as the net income from i-year-old trees, as expected in year t, and age I as the age for replanting. Then the NPV from the net income from 1 ha of cocoa in year t for one cycle of I years duration amounts to:

$$NPVONE_{I,t} = \sum_{i=0}^{I} \frac{INC_{i,t}}{(1+r)^i} \tag{13}$$

To convert $NPVONE_{I,t}$ into the NPV of an expected net income from an everlasting series of I years, $NPVINF_{I,t}$, $NPVONE_{I,t}$ is divided by $1 - 1/(1 + r)^I$, which results in:

$$NPVINF_{I,t} = \frac{NPVONE_{I,t}}{1 - \dfrac{1}{(1+r)^I}} \tag{14}$$

The decision rule with regard to the optimum tree age for replacement is that tree age I is preferred to tree age $I - 1$ if the NPV of an expected net income from an everlasting series of trees replanted at age I is higher than the NPV of an expected net income from an everlasting series of trees of age $I - 1$. In particular, $NPVINFMAX_{I,t}$ is the NPV of that tree age I for which the expected net income from an everlasting series reaches its maximum. This stipulates that for the calculation of $NPVINFMAX_{I,t}$ it is necessary to know the expected net incomes from i-year-old trees in year t for all tree ages i (Eq. 13). They are different for old and new planting material. The expected net income in year t when only old planting material is available is:

$$INC_t^B = \sum_{i=1}^{l} \left(REV_{i,t}^B - TC_{i,t}^B \right) \tag{15}$$

where $REV_{i,t}^B$ is the expected revenue from i-year-old trees of old planting material in year t. The expected net income in year t from trees of new planting material is derived analogously:

$$INC_t^W = \sum_{i=1}^{l} \left(REV_{i,t}^W - TC_{i,t}^W \right) \tag{16}$$

$REV_{i,t}^W$ corresponds to the expected revenue of i-year-old trees from new planting material in year t. The expected revenues are obtained by multiplying the corresponding normal yields for each tree age i, NY_i^B and NY_i^W, by the corresponding producer price in year t when old and new planting material are supplied, PP_t^B and PP_t^W:

$$REV_{i,t}^B = NY_i^B PP_t^B \tag{17}$$

$$REV_{i,t}^W = NY_i^W PP_t^W \tag{18}$$

Both the NPV of an expected net income from 1 ha of old planting material in year t for an everlasting series of cycles of I years, $NPVINF^B_{i,t}$, and from 1 ha of new planting material $NPVINF^W_{i,t}$ are calculated analogously to Eq. 14.

THE ECONOMIC SURPLUS MODEL FOR A RESEARCH-INDUCED PIVOTAL SHIFT OF THE SUPPLY FUNCTION

Whereas the measurement of the economic surplus of research benefits for a parallel shift of the supply function is provided by Alston, Norton and Pardey (1995, Section A5.1.2.), no description for the corresponding calculation in the case of a pivotal shift (Figure 1) is available in the literature. The effect of a pivotal instead of a parallel shift is that the slope of the supply function with the new planting material, $\beta^{I,W}_t$, is not constant but changes over time. As a consequence, the intercept of the supply function with the quantity axis when the new planting material is adopted, $\alpha^{I,W}_t$, the form of the supply function itself when the new planting material is adopted, $QS^{I,W}_t$, the computation of the market-clearing rules and the market-clearing price with new planting material, P^W_t, and the measure of changes of producer surplus, $\Delta PS_{c,t}$, have to be computed in a different way for a pivotal shift of the supply function compared with a parallel shift. However, no modifications are necessary in the situation where only old planting material is available.

In the case of a pivotal shift, $QS^{I,B}_t$ rotates by k_t (or bi in Figure 1) in its intercept j with the price axis. The intercept when new planting material is adopted is calculated from the following three values:

- the price P'_t (or point h in Figure 1) which corresponds to $P^B_t - k_t$
- the price P''_t (or point j in Figure 1), which is at the intercept of the supply function $QS^{I,B}_t$ with the price axis resulting in $-\alpha^{I,B}_t / \beta^{I,B}_t$
- the quantity supplied at the market-clearing price P^B_t before the adoption of the innovation ($QS^{I,B}$ in Figure 1).

From this the slope of the supply function in year t when new planting material is adopted can be calculated as:

$$\beta^{I,W}_t = QS^{I,B}_t / \left[P^B_t - k_t) - (-\alpha^{I,B}_t / \beta^{I,B}_t) \right] = QS^{I,B}_t / (P^B_t - k_t + \alpha^{I,B}_t / \beta^{I,B}_t) \tag{19}$$

Knowing the point P''_t on $QS^{I,W}_t$ and the slope $\beta^{I,W}_t$ of the function allows the computation of the intercept:

$$\alpha^{I,W}_t = -\beta^{I,W}_t P''_t = -\beta^{I,W}_t \left(-\alpha^{I,B}_t / \beta^{I,B}_t \right) = \left(\alpha^{I,B}_t QS^{I,B}_t \right) / \left[\beta^{I,B}_t \left(P^B_t - k_t \right) + \alpha^{I,B}_t \right] \tag{20}$$

The surplus change for producers is measured as the difference between the surplus after adoption of the innovation and the surplus before adoption. In Figure 1, this difference corresponds to the difference between the areas of the triangles $P^W gj$ and $P^B bj$. The surplus of the producers in country c and year t when only the old cultivar is available amounts to:

$$PS^B_{c,t} = QS^B_{c,t} 0.5 \left(P^B_{c,t} - P''_{c,t} \right) \tag{21}$$

Table 1. Initial parameterization and initial values for the year 1995

Parameter	Malaysia	Rest of the World
World market price P^B_{1995} (\$/t)[a]	1433.3	
Cocoa bean export (000 t)[b]	52.5	
Cocoa bean import (000 t)[b]	39.7	
Quantity demanded QD^B_t (000 t)[c]	92.2	2638.9
Quantity supplied QS^B_t (000 t)[d]	105.0	2626.1
Elasticity of supply ε (relative)[e]	0.57	0.35
Elasticity of demand η (relative)[f]	–0.47	–0.27
Population growth rate (relative)[g]	0.026	0.017
Income growth rate (relative)[h]	0.062	0.029
Income elasticity (relative)[i]	0.30	0.49
Growth rate of demand (relative)[j]	0.045	0.031
Growth rate of supply (relative)[k]		0.020

Sources:
[a]ICCO (1995).
[b]ICCO (1996).
[c]Malaysian demand: difference between supply minus exports plus imports. Demand of the ROW: difference between total demand (ICCO 1996) minus demand in Malaysia.
[d]Malaysian supply: Burger and Smit (1997a); supply in the ROW: difference between total world supply (ICCO 1996) and the supply in Malaysia.
[e]Burger and Smit (1997a) for Malaysia; Evans, Goldin and van der Mensbrugghe (1992) for the ROW.
[f]ICCO (1993) for Malaysia; Evans, Goldin and van der Mensbrugghe (1992) for the ROW.
[g]UNDP, DGVN (1994).
[h]Average annual GDP per capita growth rates are used as a measure of future income growth rates. It is assumed that growth rates for the period 1980–93 (World Bank 1995) will continue in the future.
[i]ICCO (1993).
[j]The growth rate of demand equals the population growth rate plus the product of income elasticity multiplied by the income growth rate (Alston, Norton and Pardey 1995).
[k]Burger and Smit (1997a).

The surplus of the producers in country c and year t with the improved cultivar available corresponds to:

$$PS^W_{c,t} = QS^W_{c,t} 0.5\left(P^W_{c,t} - P''_{c,t}\right) \tag{22}$$

The comparison between the two situations yields:

$$\Delta PS_{c,t} = 0.5\left[QS^W_{c,t}\left(P^W_{c,t} - P''_{c,t}\right) - QS^B_{c,t}\left(P^B_{c,t} - P''_{c,t}\right)\right] \tag{23}$$

The parameters of the supply-and-demand equations are defined by beginning with initial values for quantity demanded, quantity produced, producer price, consumer price, elasticity of supply and elasticity of demand. They are given in Table 1. Production systems, bean yield and production cost are described in Gotsch (1999) as well as a range of regressions estimating new plantings as a function of the NPV of expected incomes from investments in cocoa are presented for varying time horizons of expectation formation.

RESULTS

In this section, the theoretical model is implemented for Malaysia on the one hand and all other countries as an aggregate (ROW) on the other hand. The effects of the adoption of new planting material with improved resistance, resulting in a 20% yield increase and reduced crop protection requirements, respectively, are compared with the situation where no such planting material is available and a parallel and a pivotal shift of the supply function are assumed, respectively. The time horizon investigated is 30 years.

From Figure 2, it can be seen that the annual area newly planted with cocoa when only old planting material is available (*New plantings old*) continuously increases from approximately 16,000 ha in the first year of the simulation period to roughly 33,000 ha in the last year. When new planting material is available (*New plantings new*), the annual areas newly planted increase from about 26,000 ha in the first year to approximately 37,000 ha in the last year. Since only minor differences in the annual area newly planted can be found when a pivotal shift of the supply function is assumed, only the areas newly planted when a parallel shift of the supply function is assumed are shown in Figure 2. The continuing increase of area newly planted over time can be explained by steadily increasing producer prices, also depicted as *Price* in Figure 2. In the period under consideration, real producer prices — which are the same as the world market price because no market intervention and no freight costs are assumed — increase from \$1477 to \$2610 when only old planting material is available and from \$1478 to \$2596 with new planting material for a parallel shift of the supply function and to \$2595 for a pivotal shift of the supply function. Because the price effect of the adoption of new planting material is so small, the development of world market prices with a parallel or pivotal shift are not shown separately. The continuing price increase can be explained by the fact that world cocoa demand in the ROW grows faster compared with cocoa supply (3.1% vs. 2%). This price increase is in line with the forecast made by other authors (for instance, ICCO 1993). To take into account the effect of differences in demand growth rates, the effect of a relatively fast growth in supply of ROW compared with demand is investigated within the scope of the sensitivity analysis by Gotsch (1999). It can further be expected that the use of the vintage model approach also in the ROW, instead of constant supply-and-demand growth rates, would allow an adjustment of production capacity as a reaction to increasing producer prices in the ROW too, and hence result in a cyclic movement of the world market price. UNCTAD (1991), for instance, reports a length of cycle of 22 years.

From Figure 3, it can be seen that with old planting material (labeled *Supply old*) cocoa supply in Malaysia increases from about 89,000 t in the first year to 306,000 t in year 30, which signifies an increase in supply of approximately 3.5 times. Since differences in supply assuming a pivotal supply shift due to the adoption of new planting material instead of a parallel shift could not be visualized in Figure 3, because the differences are small, supply with new planting material is depicted only for a parallel shift. This increase is even more pronounced when new planting material is available, when the supply grows from 87,000 t to 322,000 t in the period under consideration when a parallel shift of the supply function is assumed and to 324,000 t when a pivotal shift of the supply function is assumed (*Supply new*). This generally observed trend of supply growth is — as discussed in the previous paragraph — the result of relatively fast growth in demand in the ROW compared with supply, which causes a rise in world market price and makes cocoa production more profitable.

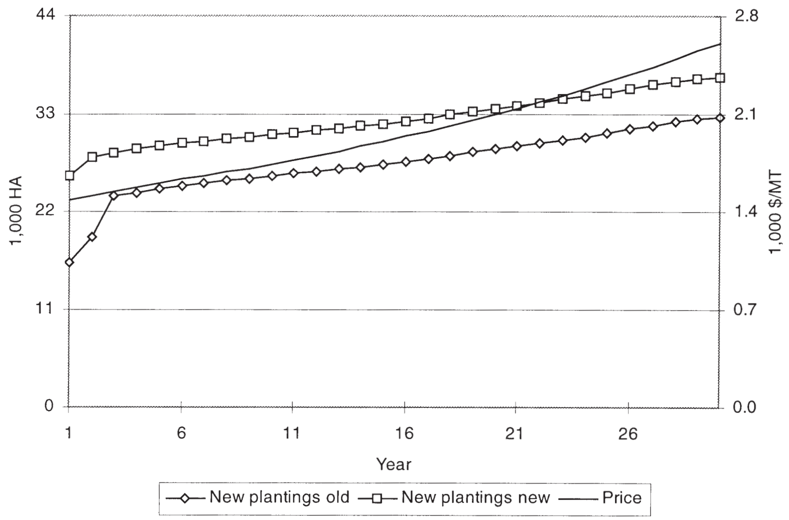

Figure 2. Areas newly planted with old planting material and with new planting material and development of world market price

Figure 4 shows the welfare effects generated for different social groups by the adoption of cocoa cultivars with improved resistance to insects, pests and diseases in Malaysia both for that country and for the ROW when a parallel shift of the supply function is assumed. From the fifth year of the simulation period, producers in Malaysia realize benefits that amount to \$1.2 million in that year and which constantly increase to \$123.2 million in the thirtieth year (labeled *Delta PS Mal.*). Welfare losses by producers from years 1 to 4 can be explained by the fact that the relative increase in area newly planted when new planting material is available is higher than the relative cost savings for new planting material compared with old planting material. As a result of a low bean yield or none at all during the first four years after planting, the positive yield effect of resistant cultivars does not occur, which means that the supply function does not shift down but up in these years. As can be expected from theory, producers in the ROW realize considerable losses from the adoption of improved planting material in Malaysia — with the exception of years 1 to 4. These losses (*Delta PS ROW*) amount to \$1.6 million in year 5 and rise to \$79.8 million in year 30. This is the result of a reduced world market price and reduced supply in the ROW compared with the situation where only old planting material is available. Consumers in both countries benefit from the adoption of new planting material as from year 5. The benefits of consumers in Malaysia (*Delta CS Mal.*) are at a relatively low level, starting with \$0.1 million in year 5 and reaching \$3.9 million in year 30, whereas the corresponding values for the ROW (*Delta CS ROW*) are \$1.5 million and \$80.4 million, respectively. Summing welfare effects for producers and consumers in each country produces the changes in total surpluses. For Malaysia considerable gains, between \$1.3 million in year 5 and \$127.1 million in year 30, are calculated (*Delta TS Mal.*), whereas the total surplus for the ROW (*Delta TS ROW*) is only slightly above zero, due to the compensation of welfare gains to the consumers by welfare losses to the produc-

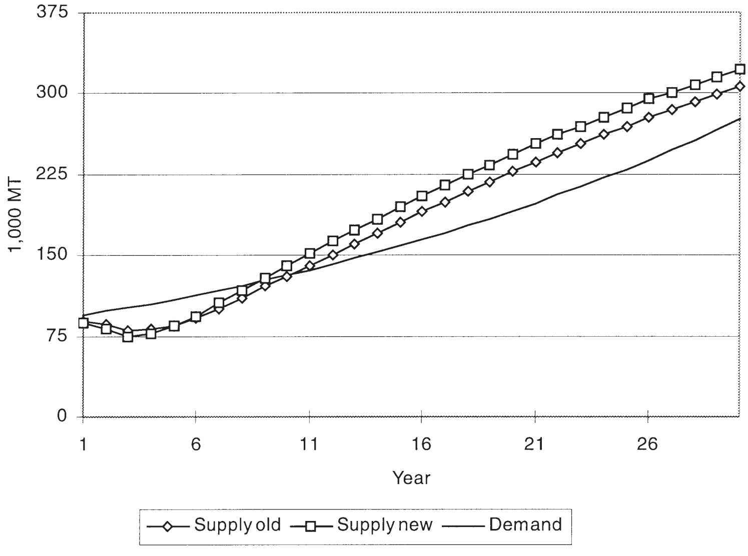

Figure 3. Supply and demand in Malaysia with old planting material and with new planting material

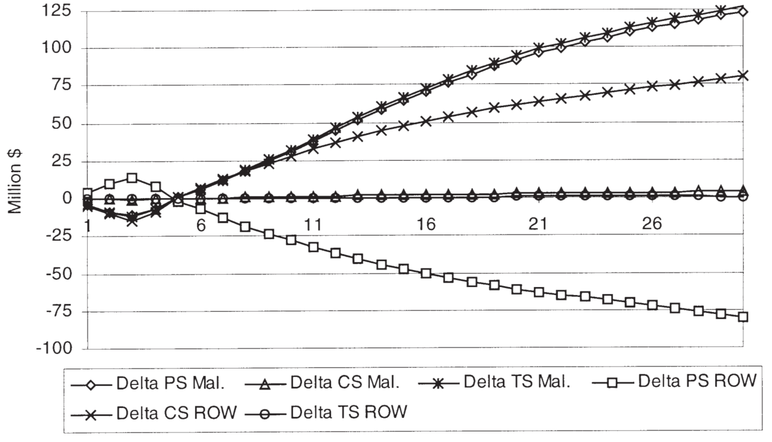

Figure 4. Welfare effects in Malaysia (Mal) and the Rest of the World (ROW) of a parallel shift of the supply function as a result of the adoption of new planting material in Malaysia

ers of about the same amount, which means a redistribution of welfare from producers to consumers with only insignificant net gains.

Finally, Figure 5 depicts the results of the welfare economic calculations assuming a pivotal shift instead of a parallel shift of the supply function as a result of the adoption of new planting material. The most significant difference is that the research benefits for producers in Malaysia are about half the size when a pivotal shift of the supply function is assumed instead of a parallel shift (*Delta PS Mal.*). From year 5 of the simulation period to year 30

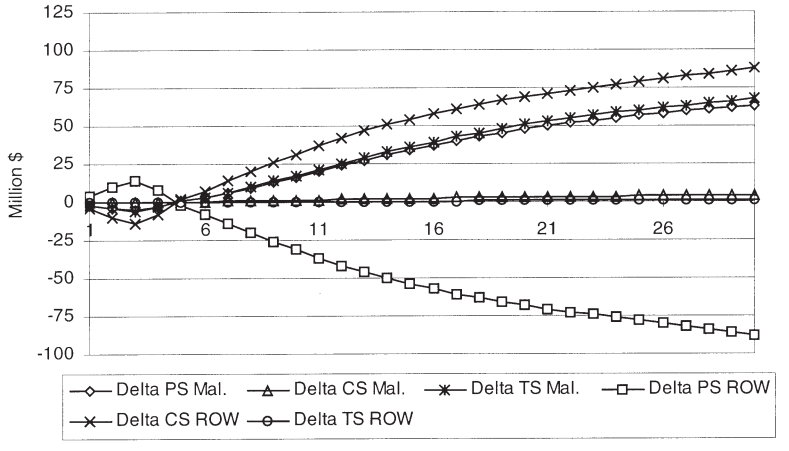

Figure 5. Welfare effects in Malaysia (Mal) and the Rest of the World (ROW) of a pivotal shift of the supply function as a result of the adoption of new planting material in Malaysia

producers gain between $0.6 million to $63.4 million. The effects on producers and consumers in the ROW and on consumers in Malaysia are stronger when a pivotal shift is assumed instead of a parallel shift: producer losses in the ROW increase from $1.6 million in year 5 to $87.7 million in year 30, whereas the consumer gains in the ROW and Malaysia are greater, increasing from $1.6 million to $88.3 million in the ROW and from $0.1 million to $4.2 million in Malaysia. As a consequence, the total welfare changes in the ROW are close to zero, as already observed, in the case of a parallel shift of the supply function, whereas total welfare gains in Malaysia are cut by about half when a pivotal instead of a parallel shift of the supply function is assumed. This finding is in line with our theoretical considerations above.

The calculation of NPVs is suggested as a means of aggregating annual benefits from the new planting material for the entire period investigated in the model — 25 years of research lag plus 30 years of simulation period. Table 2 shows that overall benefits for producers in Malaysia of $299.6 million result when a parallel shift of the supply function is assumed, whereas $156.1 million are calculated in the case of a pivotal shift of the supply function. The corresponding aggregate losses of producers in the ROW are $207.2 million and $233.3 million. The second column shows the aggregate gains by consumers. The differences in consumer gains between a parallel and a pivotal shift of the supply function are less pronounced than for producers. Under both assumptions, the greater share of welfare gains goes to the consumer.

Since NPVs are the sums of discounted annual changes of producer, consumer, and total surplus, the ratios between NPVs for these three groups are similar to the ratios between the corresponding surplus changes. The relatively low NPVs compared with annual changes in surpluses, in particular in later years of the simulation period, can be explained by the fact that large changes in surpluses arise in the relatively distant future, when the effect of discounting carries more weight compared with earlier years of the period investigated, when only relatively small gains and losses arise.

Table 2. Net present values of producer, consumer and total surpluses (PS, CS, TS) in Malaysia and the Rest of the World (in millions of dollars) from the adoption of new planting material and a parallel and pivotal shift of the supply function

Country/type of supply shift	*PS*	*CS*	*TS*
Malaysia, parallel shift	299.6	9.0	308.6
Malaysia, pivotal shift	156.1	10.1	166.2
Rest of the World, parallel shift	–207.2	208.9	1.7
Rest of the World, pivotal shift	–233.3	235.2	1.9

CONCLUSION

In this paper, a comparative-static welfare model for the *ex ante* measurement of research benefits resulting from the adoption of innovations developed by Alston, Norton and Pardey (1995) is adapted to the biological and economic characteristics of perennial crops. Since perennials require considerable fixed investments, the framework is first modified to account for the dynamics of supply response. Furthermore, the framework is adapted to integrate biological characteristics of perennial crops into the welfare economic model by taking into account the effects of the gestation lag and the variation of tree productivity over time on supply and the shifts of the supply function when improved cultivars are adopted. Different adoption rates of improved cultivars and parallel as well as conservative, pivotal types of supply shifts are assumed in the welfare calculations. The economic surplus model for a pivotal research-induced shift of the supply function as a result of the adoption of improved cultivars, which could not be found in the literature, is derived in this paper. The theoretical model is empirically implemented for adoption of improved cultivars for cocoa production in Malaysia.

An important result of the empirical analysis for Malaysia is the relatively small price and quantity effects resulting from the adoption of new cultivars. Although the price and quantity effects are small, significant benefits occur for both Malaysian producers and consumers, the magnitude of the effects depending upon whether the supply curve shifts in a parallel or pivotal manner. The advantageous results for Malaysia stem from the fact that, first, this country has a relatively low world market share, and thus increases in supply due to the adoption of improved planting material have little effect on the world market price. Second, the world market situation is favorable. Thus, with the world market prices high and with no technology spillover, the innovation will not be adopted by the ROW (which would cause an increase in supply in the ROW and, hence, reduce the attractiveness of the innovation for Malaysia).

While producers and consumers in Malaysia gain from adoption of improved planting material in Malaysia, consumers' gains in the ROW are approximately offset by producers' losses in the ROW. This suggests that, because these consumers are mainly cocoa processors, chocolate producers and consumers in the economically well-developed northern hemisphere, a considerable share of the welfare gains of biotechnical progress would benefit the latter group of countries partly at the expense of producers in countries that do not immediately adopt improved cultivars.

To make the model a useful instrument for research priority setting, a further disaggregation of the ROW into several producer countries would facilitate the welfare analysis of the important dynamic aspects of cocoa. In addition, such a disaggregation, accounting for vintage effects, would result in the characteristic cyclic price movements found by other authors for perennial crops (for instance, UNCTAD 1991). More disaggregate models would indicate more precisely the optimal timing of innovation generation and farm implementation of new technology.

Historically, considerable differences in the diffusion process of new cocoa production technology are found between different producer countries. These differences will essentially influence the total welfare of producers and affect the distribution of welfare gains and losses among producer countries. A further development policy implication of the model results lies, therefore, in the dynamic aspects of changes in the amount and distribution of welfare gains to producer countries adopting the innovation and welfare losses of nonadopter or late-adopter producing countries.

NOTES

[1]This can be explained as follows: the supply function corresponds to the aggregate of individual marginal cost curves of firms. Hence, the slope of the supply function (a marginal increase in supply) corresponds to a change in marginal cost when supply increases marginally: $dP/dq = dMC/dq$. Supply elasticity is defined as $\varepsilon = dq/dP \cdot P/q$. Solving for dP/dq results in $dP/dq = P/q \cdot 1/\varepsilon$. Substituting into the first equation above results in $dMC/dq = P/q \cdot 1/\varepsilon$. Multiplying by dq and dividing by P results in $dMC/P = dq/q \cdot 1/\varepsilon$. The left-hand side of the equation corresponds to the change in marginal cost relative to price and the right-hand side to the relative change in quantity divided by ε.

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