WORKING PAPER

The national bioenergy investment model

Technical documentation

Eric Kemp-Benedict

CIFOR

Working Paper 88

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Eric Kemp-Benedict
Stockholm Environment Institute (SEI)

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Eric Kemp-Benedict, E. 2012 The national bioenergy investment model: Technical documentation. Working Paper 88. CIFOR, Bogor, Indonesia.

Cover photo: Jeff Walker/CIFOR.
The opening of land for large-scale jatropha plantations often displaces traditional land use practices such as shifting agriculture, charcoal burning, and collection of non-timber forest products. Zambia, June, 2010.

This report has been produced with the financial assistance of the European Union, under a project entitled, 'Bioenergy, sustainability and trade-offs: Can we avoid deforestation while promoting bioenergy?' The objective of the project is to contribute to sustainable bioenergy development that benefits local people in developing countries, minimises negative impacts on local environments and rural livelihoods, and contributes to global climate change mitigation. The project aims to achieve this by producing and communicating policy relevant analyses that can inform government, corporate and civil society decision-making related to bioenergy development and its effects on forests and livelihoods. The project is managed by CIFOR and implemented in collaboration with the Council on Scientific and Industrial Research (South Africa), Joanneum Research (Austria), the Universidad Nacional Autónoma de México and the Stockholm Environment Institute. The views expressed herein can in no way be taken to reflect the official opinion of the European Union.

CIFOR
Jl. CIFOR, Situ Gede
Bogor Barat 16115
Indonesia

T +62 (251) 8622-622
F +62 (251) 8622-100
E cifor@cgiar.org

www.cifor.org

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Acknowledgements

Funding for the model was provided by the European Commission (EC), the United States Agency for International Development (USAID), and the Swedish International Development Cooperation Agency (Sida). Laura German, from CIFOR, and Graham von Maltitz, from CSIR, provided essential intellectual input at all stages. George Schoeneveld and Pablo Pacheco of CIFOR, and Francis X. Johnson of SEI, gave incisive critiques of the model. Jacqueline Senyagwa of SEI reviewed the model and helped improve its relevance for an African context, and Kendall Webster, a Tufts University graduate student, carried out research on investor decision making. Finally, members of the SADC Biofuels Task Force, chaired by Freddie Motlhatlhedi, the SADC Senior Program Officer for Energy, provided conceptual insights and critical feedback.

1. Introduction

The model described in this working paper, the National Bioenergy Investment Model (NBIM), simulates the decisions of domestic and international direct investors on whether to invest in biofuel projects in a developing country. The model can inform scenarios that assess the potential contribution of biofuel production to national development goals. It can also be run interactively, with users specifying policy packages and trajectories for highly influential but uncertain factors, such as fossil fuel prices.

The design constraints for the model were set in a series of engagements with the South African Development Community (SADC) Biofuels Task Force in the context of an ongoing project on biofuels, sustainability and forests, funded by the European Commission (EC). The Center for International Forestry Research (CIFOR) led the EC biofuels project and, together with the South African Council for Scientific and Industrial Research (CSIR), collaborated closely with the Stockholm Environment Institute (SEI) on the development of the model. Several people provided substantive input into the design and structure of the model.

2. Model overview

The core logic of the model is that investment provides capital that is then combined with other factors, such as labour and land, to produce feedstocks and fuels that are sold on domestic and international markets. Investment allocations are determined by prices and perceived risks, which can be influenced, but not determined, by policymakers. Prices, demands, investment and production, are calculated using a dynamic non-equilibrium model (Ferguson 1998) that operates at a quarterly time-step. In the model, prices adjust, after a lag of one time-step, in the direction of their equilibrium level, depending on the gap between supply and demand. The model features 'myopic' investors, who make investment decisions based on current and historical prices. The components of the model are:

- simulation of investor decision making;
- simulation of domestic demand for fuels and feedstocks based on prices and income, where demands are segmented by rural and urban consumers;
- simulation of production of fuels and feedstocks, distinguished by production model;
- estimation of prices in an equilibrium-seeking framework based on the gap between production and demand.

The choice of a dynamic, non-equilibrium model is dictated by the realities of agricultural economies in developing countries (Colman and Young 1989). Markets typically clear only after a time lag, and may never be in equilibrium, while the drivers of demand are changing rapidly and causing uncertainty in many developing countries. Thus, the size of the market can change dramatically over the course of a few years. The decision to represent investors as myopic is dictated by the nature of the model: as a simulation model, rather than an optimising model, it cannot contain physically impossible features, such as investors with perfect foresight.

The model is implemented in the Vensim 5 DSS environment, and is being released under the open source Apache License Version 2.0 (the license text is in Annex 2). The model can be run in an interactive model, in which users set values for policy variables and uncertainties. The main interactive screen is shown in Figure 1. The blue line in the figure reflects the user settings, while the orange line corresponds to the default settings. The yellow areas around the default trajectories show the variability in outputs arising from uncertainty in the model parameters when run using the default settings.

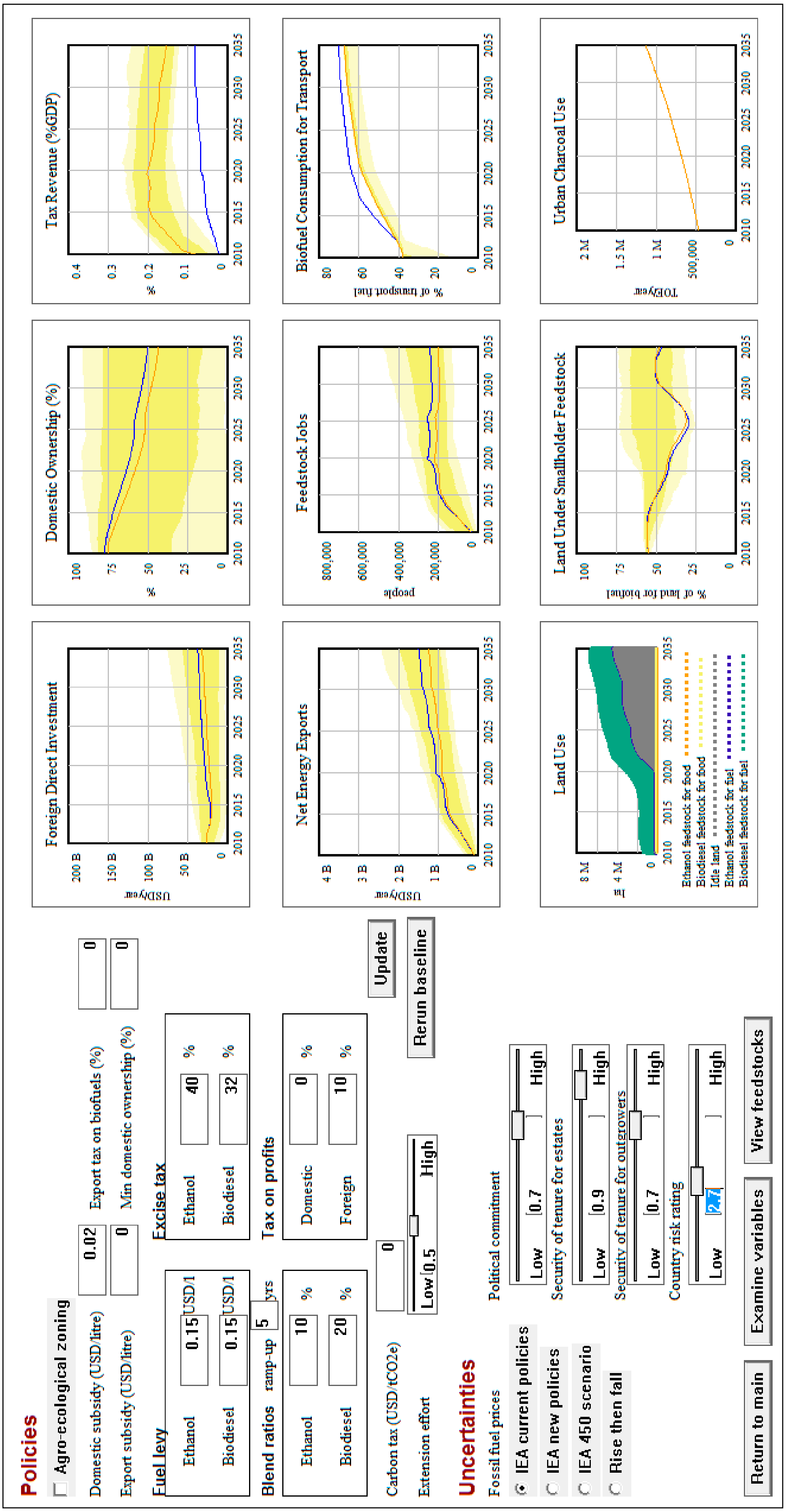

Figure 1. Main interface for interactive use

3. Investment

Investors in the model are either domestic investors or multinational enterprises (MNEs) engaging in foreign direct investment (FDI). The question the model seeks to answer is, which of a set of business models are likely to receive domestic investment funds or FDI, and in what quantities? In contrast, most research on FDI focuses on other factors, including: FDI flows to countries (rather than projects) (Asiedu 2002, Sethi *et al.* 2002, Akinkugbe 2003, Ahlquist 2006, Blonigen *et al.* 2007, Busse and Hefeker 2007, Jinjarak 2007, Lim 2008, Dippenaar 2009); mode of entry (Kogut and Nath 1988, Hennart and Park 1993, Li and Filer 2007, Li and Rugman 2007, Nocke and Yeaple 2007, Asmussen *et al.* 2009); the impact of FDI on host countries (Jenkins 2006, Adams, 2009, Chaudhuri 2010); and the decision making process within a particular firm (Dahlquist and Robertsson 2001, Moosa 2002, White and Fan 2006, Carlesi *et al.* 2007, Dippenaar 2009, Klier 2009, Kinda 2010). A survey of the literature on FDI identified one paper assessing the potential of projects within a portfolio to attract foreign investment (Li and Sherali 2003); however, the methodology in that paper requires detailed knowledge of the projects and is unsuitable for a simulation model.

The NBIM design draws upon recommendations made to the managers of MNEs (Solnik 2000, Moosa 2002, White and Fan 2006, Klier 2009) and the practices used by financial officers (Graham and Harvey 2001). In practice, MNE management might examine a variety of metrics for a project – net present value, adjusted present values, internal rate of return – and consider a variety of factors, including the firm's debt position, the size of the planned investment, its strategic importance and the strategies of competing firms, and risks at the industry, country, firm, and project level. However, much of the information that enters into investment decisions is proprietary, and it is impossible to capture all of these considerations in a simulation model. Accordingly, we base the simulation of the investment decision on one indicator – the profitability index – and then mathematically 'blur' the investment flows among different projects to account for the additional information that would be used by an MNE but that does not enter the model estimate.

3.1 Business models

Business models are specified in the NBIM by the quantity of inputs they require, such as capital, land and labour, to produce a certain amount of output – feedstock, biofuel and by-products. Production processes are assumed to combine resources in fixed proportions (that is, they are characterised by Leontief production functions). The quantity Q_i of input [i] required to produce an amount [F] of some output, whether feedstock or biofuel, is therefore given by a constant ratio, the productivity [π_i],

$$Q_i = \frac{1}{\pi_i} F. \tag{1}$$

Because resources are combined in fixed proportions, a capital investment [I] in a business model that is operating at full capacity corresponds to a definite amount of output, determined by the capital productivity [π_K],

$$F = \pi_K I. \tag{2}$$

Combining equations 1 and 2, the amount of input required to produce the output that corresponds to an investment [I] is

$$Q_i = \frac{\pi_K}{\pi_i} I\,. \tag{3}$$

The initial expenditure for biofuels is the up-front investment [I]. For feedstocks, an initial land purchase is also required. The area [A] of land that corresponds to an initial investment [I] is determined by the ratio of the productivities, as in Equation 3,

$$A = \frac{\pi_K}{\pi_N} I, \tag{4}$$

where the conventional notation N is used to indicate land. If the land price at the time of purchase is p_N, then the up-front expenditure for feedstocks is $I + p_N A$. Thus, using Equation 4, up-front expenditure [$X_{\text{up-front}}$] is

$$X_{\text{up-front}} = \begin{cases} I & \text{for biofuel operations} \\ \left(1 + \frac{\pi_K}{\pi_N} p_N\right) I & \text{for feedstock operations.} \end{cases} \quad (5)$$

Following the initial investment, revenue in each time period [t] depends on the prices of inputs [$p_{i,t}$] in that time period. In the model, only the inputs capital, land, labour and biofuel feedstock are tracked explicitly. Other inputs are collected into a single term for all other recurring costs. The revenue stream over time is given as income net of costs,

$$R_t = \left(p_{\text{prod},t} + v_{\text{by}}\right) F_t - \sum_{i=1}^{N} p_{i,t} Q_i - c_{\text{recur},t} F_t. \quad (6)$$

In Equation 6, income is given as the sum of the product price and the value of by-products per unit of output [v_{by}], multiplied by the output in each time period [F_t]. Costs are given by the total of inputs that are explicitly tracked, such as feedstocks and labour, and all remaining recurring costs [$c_{\text{recur},t} F_t$], where $c_{\text{recur},t}$ is recurring costs per unit of output. Using Equation 1, Equation 6 can be rewritten

$$R_t = \left(p_{\text{prod},t} + v_{\text{by}} - \sum_{i=1}^{N} \frac{p_{i,t}}{\pi_i} - c_{\text{recur},t}\right) F_t. \quad (7)$$

Equation 7 gives the actual revenues over time, as calculated in the model. During a model run, total output from a particular business model might fall below its full capacity, while prices of products and inputs change over time. As indicated by the notation, the value of by-products per unit of output is assumed to not change over time, while recurring costs can change.

Investors cannot know the future revenue stream of an investment with any certainty. Instead, they form an expectation of the future revenue stream [R_{expect}]. In the model this is given as

$$R_{\text{expect}} = \left(\bar{p}_{\text{prod}} + v_{\text{by}} - \sum_{i=1}^{N} \frac{p_i}{\pi_i} - c_{\text{recur}}\right) \pi_K I. \quad (8)$$

By equating the expected value of F_t with $\pi_K I$, using Equation 2, the model assumes that investors expect production to always be at full capacity. Prices and recurring costs are assumed to be at the level that prevails when the investment decision is taken, which is indicated in this equation by dropping the time index. For biofuels, the expected price for the product is the price at the time of the investment. However, for feedstocks, the expected product price is smoothed over previous time-steps, to take into account the delay between an investment in feedstock production and actual production; this is indicated by the overbar on the product price. Specifically, for a feedstock crop that takes D time-steps to mature, $\bar{p}_{\text{prod}}$ at time [t] is given as

$$\bar{p}_{\text{prod},t} = \bar{p}_{\text{prod},t-1} + \frac{1}{D}\left(p_{\text{prod},t-1} - \bar{p}_{\text{prod},t-1}\right). \quad (9)$$

3.1.1 Feasible combinations of investors and business models

There are two kinds of investor, international and domestic, and, separately for fuels and feedstocks, two classes of business model. Aside from the specific feedstock that is produced or consumed, feedstock business models can be outgrower or estate, while biofuel business models can be small-scale or large-scale. The model assumes that only certain combinations of investor type and business model are possible. While the user can change these settings, by default the model assumes that any investment option is possible except that international investors do not invest in small-scale fuel production operations.

3.2 Profitability

The question for the investor is, which of several potential investments, represented by business models, will yield the highest profit. In practice, investors might use one of several metrics to estimate potential profitability, but all of them rely on a calculation of the net present value (NPV), which is the value of the future stream of income discounted to the present, net of the original investment (Moosa 2002).

The simplest form for NPV [n_0] is

$$n_0 = R_{\text{expect}} \sum_{t=D+1}^{T} \frac{1}{(1+r)^t} - X_{\text{up-front}}, \quad (10)$$

where T is the time period of the investment and r is the discount rate. In the model, the discount rate is set equal to the equity cost of capital – that is, the return that a lender would expect to receive from a capital loan. The sum over the time index [t] begins after a delay of time [D] for crops to mature.[1]

Equation 10 is the simplest expression of NPV. The model uses a more complete formula that takes into account taxes on profit, and depreciation. The net present value [n] of an investment [I] in a business model is calculated within the model by the following formula:

$$n = (1-\tau)R_{\text{expect}} \sum_{t=D+1}^{T} \frac{1}{(1+r)^t} + \tau\delta I \sum_{t=1}^{T} \frac{(1-\delta)^t}{(1+r)^t}$$

$$\frac{1-\tau}{(1+r)^T} S - X_{\text{up-front}}. \tag{11}$$

The first term in the sum on the right-hand side of Equation 11 is the discounted stream of net benefits, as in Equation 9, but now reduced by the tax rate [τ]. The second term is the tax rebate for depreciation, where δ is the depreciation rate; this term accounts for the common rule that taxes are not paid on reasonable depreciation of capital equipment, which is treated as a loss. The third term is the discounted salvage value after depreciation over the lifetime of the investment,[2] where the salvage value [S] is given as the depreciated value of the initial investment plus the cost of land for feedstock operations,

$$S = \begin{cases} (1-\delta)^T I & \text{for biofuel operations} \\ \left[(1-\delta)^T + \frac{\pi_K}{\pi_N} p_N\right] I & \text{for feedstock operations.} \end{cases} \tag{12}$$

The sums over the time periods from one to [T] of the investment in Equation 11 start from the first time-step after the initial investment, $t = 1$, assuming a one time-step delay between investment and the receipt of income. The sums can be done explicitly using standard techniques. The relevant formula is:

$$\Sigma_T(x) \equiv \sum_{j=1}^{T} x^j = x\frac{1-x^T}{1-x}. \tag{13}$$

Applying this formula, and dividing through by the initial investment [I] gives the following key result:

$$\frac{n}{I} = (1-\tau)\frac{R_{\text{expect}}}{I}\left[\Sigma_T\left(\frac{1}{1+r}\right) - \Sigma_D\left(\frac{1}{1+r}\right)\right] +$$

$$\tau\delta\Sigma_T\left(\frac{1-\delta}{1+r}\right) + \frac{1-\tau}{(1+r)^T}\frac{S}{I} - \frac{X_{\text{expect}}}{I}, \tag{14a}$$

where

$$\Sigma_T(1+r) = \frac{(1+r)^T - 1}{r(1+r)^T}, \tag{14b}$$

$$\Sigma_T\left(\frac{1-\delta}{1+r}\right) = \frac{(1+r)^T - (1-\delta)^T}{(r+\delta)(1+r)^T}. \tag{14c}$$

Equations 14a–c are used in the model to determine the optimal investment strategy. The expression $1 + n/I$, the 'profitability index', is a standard metric for deciding on the profitability of a potential investment (Moosa 2002).[3] For convenience, we refer to the right-hand side of Equation 14a as $\Phi_{\text{model}}(r;\tau,\delta)$,

$$\frac{n}{I} \equiv \Phi_{\text{model}}(r;\tau,\delta), \tag{15}$$

where the subscript 'model' indicates that the factor is dependent on the business model. As indicated by the notation, it also depends on the tax and depreciation rates. Also as indicated, it does not depend on the initial investment [I] because in equations 5, 8, and 12, R_{expect}, S, and $X_{\text{up-front}}$ are proportional to I. This convenient result is a consequence of using Leontief production functions.

1 Equation 10 simplifies the reality of starting a new enterprise, which at a minimum includes an establishment or transitional phase that is quite distinct from the operating phase. In principle, it is not difficult to adapt the model to handle these additional details. However, it is unlikely that the necessary data will be available.

2 Note that depreciation is used in this formula in a conventional way to estimate the future value of equipment for tax purposes and salvage. The same depreciation rate is also used elsewhere in the model as the rate at which capital is permanently removed from productive use. This removal can occur for reasons other than ordinary wear-and-tear of equipment, such as insolvency, mismanagement and catastrophic damage, and so its rate does not have to equal the capital depreciation rate used for estimating net income. The assumption that the two rates are equal is not essential to the model, but it is reasonable to assume that the rates are of a similar magnitude, and it removes the need to specify an additional parameter.

3 In a survey of financial officers, the profitability index (PI) was found to be a less popular method for evaluating projects than either NPV or the internal rate of return (IRR) (Graham and Harvey 2001). However, since NPV scales directly with the initial investment [I] – under the model assumption that output scales directly with input (Leontief production functions) – if two projects have equal initial investments, then NPV and PI will give equivalent rankings, because PI is simply NPV/I + 1. Thus, within the model, NPV and PI are equivalent. IRR may give a different ranking than PI or NPV, but IRR and PI lead to identical go/no-go decisions for an individual investment: if the PI is positive at a discount rate [r], then the IRR will be higher than r. A drawback of IRR compared to PI is that it has units of 1/time, whereas PI is dimensionless. The use of a dimensionless indicator simplifies the model for estimating financial flows that is developed in Section 3.4.

Equations 14a–c are also used in the model to calculate a threshold producer price above which the investment is attractive and below which it is not attractive. This is determined by setting $n = 0$, substituting for R_{expect} using Equation 8, and then solving for the producer price.

3.3 Investor discount rate: the equity cost of capital

The investor decision making submodel is based on financial portfolio theory, and considers both domestic and international investors to be comparing an investment in biofuel feedstock production or processing to similar investments in a larger market. In portfolio theory, risk is considered to be either systematic or non-systematic; systematic risk captures how the potential investment moves with the market as a whole, while non-systematic risk captures idiosyncratic investment, firm and location factors. In theory, investors can remove non-systematic risk through diversification, leaving only systematic risk (Solnik 2000). However, in practice, and in particular for FDI, opportunities for diversification are limited and firms routinely include non-systematic risk in their evaluation of projects (White and Fan 2006). Accordingly, in the model, investors expect a risk-adjusted rate of return [$r_{E,i}$] – the equity cost of capital – for business model i where

$$r_{E,i} = r_{\text{rf}} + \beta_i(r_{\text{ave}} - r_{\text{rf}}) + \gamma r_{\text{curr}} + \rho_{\text{macro}} + \rho_{\text{micro},i} - \theta_i. \quad (16)$$

In Equation 16, the first three terms are the international capital asset pricing model (ICAPM), which captures systematic risk (Solnik 2000): r_{rf} is the risk-free return (for example, the rate for a treasury bond); r_{ave} is the average market return; and r_{curr} is the currency risk premium for international investors. The parameter β is the risk factor, and γ is the sensitivity of the international investment to currency risk. Of the ICAPM terms, the first two apply to both international and domestic investment, and each of the parameters can differ between international and domestic markets. The third term only applies to international investors. Of the remaining four terms, the first two, ρ_{macro} and ρ_{micro}, are country risk factors – that is, factors that are under at least partial control of the government – and apply only to international investors. Macropolitical and macroeconomic risk factors are those that are shared by all international investors in the country, and are reported in international tables, such as Euromoney or IHS Global Insight. Micropolitical and microeconomic risk factors are those that are specific to an industry within the country (Moosa 2002). The term θ, which can be either positive or negative, captures irrational deviations from ideal investment behaviour (Pompian 2006). Note that both the micro risk factors and the 'irrational expectations' parameters carry an index [i]. This is because they are each affected by local conditions that are specific to a particular business model.

In general, all of the terms in Equation 16, following the first term, capture expectations of risk. The higher the risk is, the higher the return an investor will expect. This can be understood in terms of a change in the discount rate; future risks make future returns less valuable (Moosa 2002). The factors β and γ have a very specific interpretation and represent a specific kind of risk. The factor β indicates how closely aligned the returns from the investment and the market as a whole are expected to be. The factor γ represents how correlated the value of the national currency is to a basket of currencies. Thus, to the extent that the investment simply tracks the market as a whole, it fails to reduce risk through diversification. Both β and γ can be greater than one, meaning that they can magnify swings in the market; they can also be negative, if they tend to move counter to the market. For small economies, whether γ is large or not depends on whether the currency is pegged to a major currency. If it is, then γ is expected to be close to one; if not, it may be less than one, and even negative. In the model, the βs are assigned a range of values based on the available literature. As explained in Section 7, 'Parameter uncertainty', the model is run in sensitivity mode in which uncertain parameters, including the investment βs, take on values sampled from a plausible range.

3.4 Investment flows to business models

Investments in the model flow to different feedstock or biofuel business models depending on the returns provided by each business model. Non-biofuel investments compete with biofuel investments. If no biofuel investment opportunities are competitive with the alternatives, then very little biofuel investment occurs within the model.

As shown in equations 14a–c, the net present value of a business model [i] is given as the initial investment multiplied by an investment-specific function of the rate of return. In Equation 15, the factor is written $\Phi_i(r;\tau,\delta)$, so that

$$n_i = I_i \Phi_i(r;\tau,\delta). \tag{17}$$

Unlike Equation 15, Equation 17 is concerned with flows of investment to different business models, and we add a label i to both the net present value and the investment. Given the function $\Phi_i(r;\tau,\delta)$ and the risk-adjusted discount rate $r_{E,i}$ defined in Equation 16, a simple 'go/no-go' criterion for the investor is

$$\Phi_i(r_{E,i};\tau,\delta) \geq 0. \tag{18}$$

If the model were strictly true, and all investors used the profitability index to decide between investments, all investment would flow to the business model with the highest profitability index, or at least as much investment as it could absorb. However, this theoretical case is unrealistic for several reasons: not every investor will use this approach to determine whether to invest; there are factors (in particular, firm and location-specific factors) that are not captured in Equation 11; and all of the parameters are uncertain. Accordingly, rather than simply maximise profit, the model maximises a weighted sum of the average of the log profit index and an 'entropy' term, using the objective function

$$Z = (1-\varphi)\sum_{i=1}^{N} w_i u_i - \varphi \sum_{i=1}^{N} w_i \ln w_i, \tag{19}$$

where

$$u_i \equiv \begin{cases} \ln\left(\Phi_i(r_{E,i};\tau,\delta)+1\right) & , \quad \Phi_i(r_{E,i};\tau,\delta)+1 > \varepsilon \\ \ln\varepsilon & , \quad \text{otherwise} \end{cases}. \tag{20}$$

In Equation 19, the w_i are the fractions of total investment flowing to each business model. That is,

$$w_i = \frac{I_i}{\sum_{j=1}^{N} I_j}. \tag{21}$$

The second term of Equation 19 is the entropy of the distribution of investment flows – an interpretation of this term is given below. The parameter φ, which lies between zero and one (and is never exactly zero or one), expresses the relative importance of the profit-maximising and entropy terms.

Equation 20 defines u_i, the quantity to be maximised, as the natural logarithm of the profit index, unless the profit index is negative, in which case the logarithm of a very small number is substituted. The profit index becomes negative only when the revenue stream itself is negative. When the profit index equals one, u_i is equal to zero. By using the logarithm of the profit index, rather than the profit index itself, projects are compared based on their relative performance, rather than their absolute performance. If one project is expected to make twice as much profit as an alternative project, then the difference of the u_is between the two projects is the natural logarithm of two, ln(2), regardless of the level of profit of the two projects.

3.4.1 Interpretation of the objective function

The objective function can be given an information-theoretic interpretation. The first term in the objective function (Equation 19) is the average profit. In the limit $\varphi \to 0$ this becomes the dominant term and, as shown below, in this limit all investments flow to the business model with the highest profit index. In this case, an outside observer viewing the flow of investments would be able to learn which project yields the highest expected profit. As discussed earlier, several factors interfere with this ideal situation, so that the observed flow of investments does not provide perfect information about the ranking of excess returns. The second term captures this reality. In the limit $\varphi \to 1$, each business model receives the same level of investment. In this case, the objective function is the entropy, and so maximising Z means minimising the amount of information contained in the investment allocation. In this no-information limit the distribution of investment flows provides no guidance to the relative merits of the different business models. For intermediate values of φ, business models with high expected profits get the highest weights, but investments also flow to business models with lower expected profits, so that the information provided by the investment flows is ambiguous.

3.4.2 Optimal distribution of investment flows

The distribution of investment flows in the model is solved by maximising the objective function (Equation 19) subject to the constraint that the weights sum to one,

$$\sum_{i=1}^{N} w_i = 1. \tag{22}$$

Using equations 19 and 22, the objective function S for the problem can be written

$$S = (1-\varphi)\sum_{i=1}^{N} w_i u_i - \varphi \sum_{i=1}^{N} w_i \ln w_i + \lambda\left(1 - \sum_{i=1}^{N} w_i\right), \tag{23}$$

where λ is a Lagrange multiplier. Varying S with respect to the weights and setting them equal to zero (the optimal condition) gives

$$(1-\varphi)u_i - \varphi(1+\ln w_i) - \lambda = 0. \tag{24}$$

Rearranging this equation to get the weight on one side and collecting the constant terms into an overall constant $\ln A \equiv -1 - \lambda/\varphi$ gives

$$\ln w_i = \ln A + \frac{1-\varphi}{\varphi} u_i. \tag{25}$$

Exponentiating both sides of Equation 25 gives the expression for the weights,

$$w_i = A \exp\left(\frac{1-\varphi}{\varphi} u_i\right). \tag{26}$$

The value of A is then determined by the normalising constraint in Equation 22. Requiring that the weights sum to one gives

$$w_i = \frac{\exp\left(\frac{1-\varphi}{\varphi} u_i\right)}{\sum_{j=1}^{N} \exp\left(\frac{1-\varphi}{\varphi} u_j\right)}. \tag{27}$$

3.4.3 Introducing non-biofuel investments

Biofuel investment opportunities will be competing with non-biofuel opportunities that may have higher expected profits. Rather than defining these explicitly, we assume that there are [m] biofuel investments and [N] total investments, so there are N-m non-biofuel investments. As described above, all investments in the model are characterised by their log profitability [u_i]. We make the assumption that log profitability among non-biofuel investments is distributed according to some probability distribution with a probability density [$f(u)$] The expected value of the non-normalised weights can then be calculated, using the probability density as

$$\langle w \rangle = \int_{-\infty}^{+\infty} du\, f(u) \exp\left(\frac{1-\varphi}{\varphi} u\right). \tag{28}$$

This integral is equal to the moment-generating function $M_f(\cdot)$ for the probability density. The practical benefit of this is that moment-generating functions have been calculated for many probability distributions. Thus, the result for the average weight can be written

$$\langle w \rangle = M_f\left(\frac{1-\varphi}{\varphi}\right). \tag{29}$$

This expected value for non-bioenergy weights can be used to rewrite the expression for the weights in Equation 27 as

$$w_i \approx \frac{\exp\left(\frac{1-\varphi}{\varphi} u_i\right)}{\sum_{j=1}^{m} \exp\left(\frac{1-\varphi}{\varphi} u_j\right) + (N-m) M_f\left(\frac{1-\varphi}{\varphi}\right)}. \tag{30}$$

For the model, we assume that the log profitability of non-biofuel investments is distributed normally with a mean of zero – that is, it is equally likely that an investment has a positive log profitability as it has a negative profitability. In this case,

$$w_i^{\text{norm}} = \frac{\exp\left(\frac{1-\varphi}{\varphi} u_i\right)}{\sum_{j=1}^{m} \exp\left(\frac{1-\varphi}{\varphi} u_j\right) + (N-m) \exp\left[\frac{1}{2}\left(\frac{1-\varphi}{\varphi}\right)^2 \sigma_f^2\right]}. \tag{31}$$

While the assumption of a normal distribution is convenient for the model development, it is not essential. The moment-generating function can be computed explicitly for many distributions.

3.4.4 Properties of the weights

The weights in Equation 31 have some properties that are worth remarking on. Because the denominator is the same for any investment, the business model with the highest value for u_i receives the highest weight. In the limit $\varphi \to 0$, the ratio $(1-\varphi)/\varphi$ diverges, and the non-biofuel term dominates any of the biofuel business models. This is a consequence of assuming a normally-distributed set of non-biofuel options. Under this assumption there will always be some non-biofuel investment with a higher return than the biofuel investments, and in the limit $\varphi \to 0$ it will receive all of the investment flows. In contrast, in the limit $\varphi \to 1$, the ratio $(1-\varphi)/\varphi$ approaches zero, and all of the weights take the same value, equal to $1/N$. At values of φ intermediate between zero and one, the most profitable investment receives the highest weight, but other, less profitable investments are also given some weight. The weights can become very small, suggesting implausibly low levels of investment. For this reason, a minimum investment threshold is set by the user for different types of investors. If the investment allocation is less than the minimum, then the investment is set to zero in the model.

The parameter φ is a tuning parameter of the model, which has no obvious default value. For illustration, at $\varphi = 1/2$, the weights become

$$w_i^{\text{norm},\varphi=1/2} = \frac{e^{u_i}}{\sum_{j=1}^{m} e^{u_j} + (N-m)e^{\sigma_f^2/2}}. \quad (32)$$

In this case, it can be seen that biofuel investments with negative excess profits receive low weights, because they cannot outperform the positive excess return from non-biofuel investments. The investment flows for business models with negative expected profit will ordinarily fall below the minimum investment threshold, so no investment will flow to them. Also, if the total number of investments N is much larger than the number of biofuel investments m, then biofuel investments must strongly outperform the average non-biofuel portfolio to gain a substantial share. As the variance σ_f^2 of non-biofuel investments increases, potential competition from non-bioenergy investments also increases. When φ is close to zero, high-performing investments receive high weights, and when φ is close to one, even poorly-performing investments may receive a substantial weight.

3.4.5 Implementing a minimum level of domestic investment

One of the policy instruments that the model simulates is a minimum level of domestic investment. The model simulates a policy in which applications for permits from foreign investors are suspended whenever the previous quarter's statistics indicate that domestic investment is below the target. This policy characteristically leads to a 'saw tooth' pattern in foreign investment when averaged over the year. The saw tooth pattern can look odd, but it is not an unreasonable outcome, since it follows directly from the simulated policy.

4. Domestic energy demand

Domestic energy demand in the model comes from the household and transport sectors, where per capita energy demand is determined by incomes and fuel prices, subject to the possible constraint placed by a mandatory blend ratio. International demand is assumed to be so large that national production has no effect on prices (fuel prices, both domestic and international, are discussed in Section 5). Rural and urban populations can have different demand parameters, as well as different income levels and fuel prices.

Population growth in rural and urban areas, and economic growth, are given exogenously. From these, average income (as gross domestic product per capita) is calculated. Rural and urban incomes are then determined from an exogenous rural-to-urban income ratio.

4.1 Constant elasticity of substitution utility function

It is expected that biofuels and fossil fuels will coexist and be used for similar purposes for a substantial time, while ethanol can be used as an additive to petrol. That is, they do not act as perfect substitutes. However, they do not act as perfect complements – the precise mix of fossil fuels and biofuels can vary depending on relative price, technology, convenience, policy, fashion and other factors. This suggests that demands should be represented by a functional form that is intermediate between that of a perfect substitute and of a perfect complement: the constant elasticity of substitution (CES) demand function has this property. Accordingly, we assume the following CES utility function for the model:

$$U = \left[\sum_{i=1}^{M} \frac{\hat{p}_i(\vec{v})}{\varepsilon_i \eta_i} (\varepsilon_i \eta_i x_i)^{\alpha}\right]^{\frac{1}{\alpha}}. \tag{33}$$

In this function, the x_i are the quantities of fuel consumed in physical terms (litres or kilograms), the ε_i are conversion efficiencies (for instance, conversion of combustible fuels into heat in a stove), while the η_i are energy density factors that convert physical quantities into their energy equivalents. The $\hat{p}_i(\vec{v})$ are coefficients within the utility function that express the degree of preference for one fuel over another – an interpretation for these parameters will emerge in Section 4.3 that justifies the choice of notation. The $\hat{p}_i(\vec{v})$ potentially depend on a vector of parameters $[\vec{v}]$ that is currently unspecified. The parameter α is characteristic of CES utility functions and interpolates between pure-complement $(\alpha = 0)$ and pure-substitution $(\alpha = 1)$ utility functions.

4.2 Finding the optimal allocation

Consumers whose utility is described by Equation 33 are assumed to face an energy budget constraint $[B(\bar{y})]$, which grows with average income, so that

$$\textstyle\sum_{i=1}^{M} p_i x_i \leq B(\bar{y}), \tag{34}$$

where p_i are fuel prices in volumetric terms (e.g., dollars per litre). Because the utility function is strictly increasing in energy consumption, it can be assumed that the entire budget will be spent, and so the inequality (Equation 34) can be replaced with an equality,

$$\textstyle\sum_{i=1}^{M} p_i x_i = B(\bar{y}). \tag{35}$$

The consumer seeks to maximise utility subject to their budget constraint, so the objective function is

$$S = \left[\sum_{i=1}^{M} \frac{\hat{p}_i(\vec{v})}{\varepsilon_i \eta_i} (\varepsilon_i \eta_i x_i)^{\alpha}\right]^{\frac{1}{\alpha}} + \lambda\left(B(\bar{y}) - \textstyle\sum_{i=1}^{M} p_i x_i\right), \tag{36}$$

where λ is a Lagrange multiplier. In addition to the budget constraint, the optimum conditions are that

$$\frac{\partial S}{\partial x_i} = \frac{\hat{p}_i(\vec{v})}{\varepsilon_i \eta_i} \varepsilon_i \eta_i (\varepsilon_i \eta_i x_i)^{\alpha - 1} \left[\sum_{j=1}^{M} \frac{\hat{p}_i(\vec{v})}{\varepsilon_i \eta_i} (\varepsilon_i \eta_i x_i)^{\alpha}\right]^{\frac{1}{\alpha} - 1} - \lambda p_i = 0. \tag{37}$$

The most complex factor in this expression – the one in brackets – is independent of *i*. Combining all i-independent factors into an overall coefficient $[C(\vec{v})]$ that depends on the (still unspecified) parameters $[\vec{v}]$, Equation 37 can be rearranged to show that

$$\epsilon_i \eta_i x_i = C(\vec{v}) \left(\frac{\hat{p}_i(\vec{v})}{p_i} \right)^{\frac{1}{1-\alpha}}. \tag{38}$$

That is, the energy-content corrected consumption of fuels $[\eta_i x_i]$ declines as the price $[p_i]$ increases, and rises as the coefficient $[\hat{p}_i(\vec{v})]$ increases.

4.3 Reference prices

The expression on the right-hand side of Equation 38 suggests an interpretation of the utility coefficients $[\hat{p}_i(\vec{v})]$. They can be thought of as the threshold prices at which a consumer finds each fuel desirable. When the price $[p_i]$ of a fuel exceeds the coefficient value, then the ratio in parentheses in Equation 38 is less than one, reflecting its lower desirability; when the price falls below the coefficient value, then the ratio in parentheses is greater than one, reflecting desirability. The coefficients $[\hat{p}_i(\vec{v})]$ will be referred to as 'reference prices' in the rest of this document.

The reference prices can be formulated in a convenient way. If all that a consumer wanted from a fuel was the energy services it provided, then they would set their reference prices to scale with the product of efficiency and energy density $[\varepsilon_i \eta_i]$. That is, prices in terms of energy services provided should be identical. However, people look for many characteristics other than energy services in a fuel, such as convenience and the taste they impart to foods. Even for closely substitutable fuels, such as ethanol and petrol, people may in some circumstances think one of them less attractive. For example, biofuels may be thought less desirable because they have a lower energy density than their fossil equivalents, and so require more frequent fill-ups, or because they are not seen as sufficiently 'modern'. Alternatively, consumers may see biofuels as more attractive because they are seen as 'green'. For this reason, reference prices are expected to have the following form:

$$\hat{p}_i(\vec{v}) = \pi \eta_i \varepsilon_i e^{\Delta_i(\vec{v})}, \tag{39}$$

where π is a constant that is common to all fuels and $\Delta_i(\vec{v})$ reflects a relative preference for the fuel. When the preference term is positive, the reference price is higher than expected, and so the fuel will be attractive at a higher than expected price. The opposite is true when the preference term is negative.

The preference term $\Delta_i(\vec{v})$ can depend on many factors; however, the factors are expected to change systematically with income level. To take one example, when roads are poor, modern fuels that must be transported from cities to rural areas can be less convenient than traditional fuelwood. To take another example, people with low and uncertain incomes may be less able to afford an expensive but efficient device, even if it should save them money in the long term. This is consistent with the concept of the 'energy ladder', where households move through a relatively predictable sequence of fuels as their incomes increase (Hosier 1993, 2004). Preferences can also be expected to change over time, independent of income. Most importantly for this model, preferences for biofuels may change over time as perceptions about biofuels change. To capture the change in both income and time, the following formulation is used in the model:

$$\Delta_i = \Delta_{i0}(t) + \gamma_i \ln \bar{y}, \tag{40}$$

The factors γ_i are income elasticities, which might be either positive (for preferred fuels, such as liquid fuels) or negative (for less attractive fuels, such as wood). As average income increases, the reference price rises for preferred fuels and declines for undesirable fuels, as households climb the energy ladder. From equations 39 and 40 it can be seen that average income $[\bar{y}]$, and time $[t]$ are the parameters $\vec{v}$ that determine the reference prices $\hat{p}_i(\vec{v})$ and the coefficient $C(\vec{v})$, so that $\vec{v} = (\bar{y}, t)$.

4.4 Multinomial logit demand function

The normalisation coefficient $C(\bar{y}, t)$ is determined by calculating the sum in Equation 35,

$$B(\bar{y}) = C(\bar{y}, t) \sum_{i=1}^{M} \left(\frac{\hat{p}_i(\bar{y}, t)}{p_i} \right)^{\frac{1}{1-\alpha}} \frac{p_i}{\varepsilon_i \eta_i}, \tag{41}$$

where the income and time dependence of the reference prices and the normalisation coefficient are shown explicitly. Solving for $C(\bar{y}, t)$ and substituting into Equation 38 gives an expression for fuel consumption,

$$x_i = \frac{B(\bar{y})}{\varepsilon_i \eta_i} \left[\sum_{j=1}^{M} \left(\frac{\hat{p}_j(\bar{y},t)}{p_j} \right)^{\frac{1}{1-\alpha}} \frac{p_j}{\varepsilon_i \eta_i} \right]^{-1} \left(\frac{\hat{p}_i(\bar{y},t)}{p_i} \right)^{\frac{1}{1-\alpha}}. \quad (42)$$

This expression predicts that energy expenditure shares [s_i] will follow a multinomial logit model (Kennedy 2003), where expenditure shares are linked to fuel consumption [x_i] via

$$x_i = \frac{B(\bar{y})}{p_i} s_i. \quad (43)$$

In the multinomial logit model,

$$s_i = \frac{e^{z_i}}{\sum_{j=1}^{M} e^{z_j}}, \quad (44)$$

where the variables [z_i] depend on prices, average income and time. Substituting for the reference prices using equations 39 and 40, the expression for the variables z_i can be shown to be

$$z_i = \frac{\gamma_i}{1-\alpha} \ln \bar{y} - \frac{\alpha}{1-\alpha} \ln \left(\frac{p_i}{\varepsilon_i \eta_i} \right) + \frac{1}{1-\alpha} \Delta_{i0}(t) + \text{const.} \quad (45)$$

In the model, an auxiliary Excel workbook estimates the parameters in Equation 45 using data on fuel shares, fuel prices and device efficiencies in rural and urban areas. The parameters are estimated using Excel's Solver facility. For both household and transport fuels, the solver is run twice: in the first run the substitutability parameter α is set equal to 0.5; in the second run it is left free. This two-pass strategy avoids some problems when $\alpha = 1$ in Equation 45.

4.5 Implementing a mandatory blend ratio

Under a mandatory blend ratio, whenever a fossil fuel is consumed, a proportional amount of an equivalent biofuel must also be consumed. It is permissible for more of the biofuel to be consumed, but not less. If the blend ratio is r_{blend}, then the relationship between biofuel consumption [x_B] and fossil fuel consumption [x_F] is

$$x_B \geq \frac{r_{\text{blend}}}{1-r_{\text{blend}}} x_F. \quad (46)$$

This is handled in the model by replacing the fossil fuel [F] with a blend, at the mandatory blend ratio in the demand function. The equivalent to Equation 45 for the blended fuel is

$$z_{\text{blend}} = \frac{\gamma_F}{1-\alpha} \ln \bar{y} - \frac{\alpha}{1-\alpha} \ln \left(\frac{p_{\text{blend}}}{\varepsilon_F \eta_{\text{blend}}} \right) + \frac{1}{1-\alpha} \Delta_{F0}(t) + \text{const.} \quad (47)$$

That is, the price and energy density are calculated by averaging with the blending fraction, but the demand parameters γ_F and $\Delta_{F0}(t)$ and the device efficiency ϵ_F are those of the corresponding fossil fuel. Consumption of the equivalent fossil fuel and biofuel are then calculated as

$$x_F = (1 - r_{\text{blend}}) \frac{B(\bar{y})}{p_{\text{blend}}} s_{\text{blend}} \quad (48a)$$

and

$$x_B = r_{\text{blend}} \frac{B(\bar{y})}{p_{\text{blend}}} s_{\text{blend}} + \frac{B(\bar{y})}{p_B} s_B. \quad (48b)$$

This ensures that demand for the biofuel is at least at the level given by the mandatory blending target, but may also be higher if there is demand for the biofuel independent of the blending target.

5. Production and prices

Prices are determined within a dynamic equilibrium-seeking framework. In this equilibrium-seeking model, at any given time, there are potentially distinct prices for each type of consumer – rural, urban and international. Within the country, prices for each consumer category can be affected by transport costs, local demand patterns, taxes and subsidies. International prices are determined, fundamentally, by the free on-board (FOB) price of fuels as determined in international markets, but are further influenced by costs at port, domestic taxes, subsidies and tariffs.

Feedstock producers respond to the domestic price. Biofuel producers respond to an average of international and domestic prices, based on the share of total biofuel production that is exported rather than consumed domestically. That is,

producer price = export share × international price + (1 – export share) × domestic price (49)

Producers respond to prices in two ways. First, sufficiently high expected profit (which depends on prices) drives investment, leading to increased production. Second, if prices fall below operating costs, then producers reduce their production. They compare the producer price [p_{prod}] to the production cost, calculated as

$$c_{\text{prod}} \equiv c_{\text{recur}} + \sum_{i=1}^{N} \frac{p_i}{\pi_i} - v_{\text{by}}. \tag{50}$$

If the price falls sufficiently far below production costs, they reduce production [X] to a fraction of the maximum, following the curve in Figure 2.

The producer price for feedstocks is set to the domestic producer price. For biofuels, it is set to the international producer price, partly because of practical limitations of the model, but mainly because the biofuel market is directed primarily at an external market.

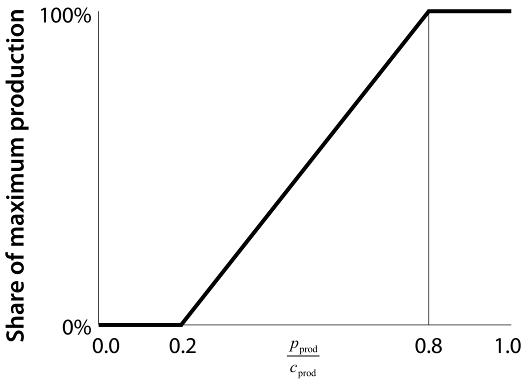

Figure 2. Production response to producer price and costs

For vertically integrated operations, production as a share of the maximum is determined by production costs relative to biofuel price. In the model, the capital flowing to feedstock production and to biofuel production in vertically integrated operations is tracked separately from investments made in strictly feedstock or strictly biofuel operations. The model distinguishes between vertically integrated and independent fuel and feedstock operations by the capital stock invested in each type of operation. Because capital stock is removed through depreciation, this accounts for the withdrawal of vertically integrated or independent operations from the market.

5.1 International fuel prices

Fossil fuel prices are set exogenously, as the price that prevails in international markets, the FOB price. It is assumed that at an international level, biofuels receive a premium or a penalty relative to the equivalent fossil fuel. For example, ethanol has about 65% of the energy density of petrol, and so the FOB price of ethanol in the model is 65% of the price of petrol, multiplied by a markup (or markdown) that captures the preference on the international market for biofuels compared to fossil fuels. This gives an adjusted FOB price. For internationally traded fuels, domestic and international producer prices are calculated as

adjusted FOB price + freight, wharfage, etc. = landed price
+ taxes and levies = domestic price
+ domestic subsidies = **domestic producer price**
adjusted FOB price + export taxes + export subsidies = **international producer price.** (51)

5.2 Domestic fuel prices

Domestic fuel prices are calculated with an equilibrium-seeking algorithm. Because most of the cross-fuel and cross-business model interactions are captured either by the investment or demand models described in previous sections, a simplified notation is used in this section to explain the algorithm. In this simplified notation most subscripts are suppressed.

Once a biofuel producing facility has been established, its maximum capacity is limited either by the availability of capital [K] or feedstock [F]. As discussed above, if the price [p] falls too low, then it will run at a fraction of its maximum capacity, so the supply of biofuel [$S(K, F, p)$] depends on K, F, and p. The demand [$D(p, y)$] is calculated as described in Section 4, based on prices [p] and income [y]. Capital [K] is lost from depreciation, with a coefficient [δ] and is increased by investment [$I(p)$], where the amount of investment depends on prevailing prices. Prices adjust upward or downward depending on whether demand is greater than or less than supply (Quandt 1988, Ferguson 1998, Hallegatte *et al.* 2008),

$$\frac{dp}{dt} = ap\frac{D(p,y) - S(K,F,p)}{D(p,y)}, \tag{52}$$

where a, which has units of inverse time, is a constant that relates excess demand to changes in price. The stock of capital changes due to investment and depreciation,

$$\frac{dK}{dt} = I(p) - \delta K. \tag{53}$$

Together, equations 52 and 53 provide a dynamic, equilibrium-seeking behaviour in which consumers and producers move toward the price at which demand and supply are equal. Since various factors influencing demand and supply change over time in the model, it is possible that the equilibrium is never reached, and is always being sought – as in many real markets.

Additional features are added to this model to capture the fact that there are different kinds of producers (large and small scale) and different markets (rural, urban and international). First, prices in any market are adjusted by transport costs. It is assumed that small-scale producers are located in rural areas, while large-scale producers are assumed to be located close to urban areas (and international ports). Thus, transport costs between small-scale producers and rural consumers are lower than those between small-scale producers and urban consumers. Second, domestic prices do not rise above international prices. For example, if a rural consumer can get a better price by buying fuel imports, despite the cost of transporting the product from a port, then they will do that, rather than buying a local product. Third, both large and small producers sell into the rural, urban and international markets, with shares determined by price. Denoting the producer price in urban areas (corrected for transport costs) as p_U, in rural areas as p_R, and internationally as p_I, a producer's urban share [s_U] is calculated as

$$s_U = \frac{e^{p_U k/p_I}}{e^{p_U k/p_I} + e^{p_R k/p_I} + e^{p_I k/p_I}}. \tag{54}$$

The rural and international shares are calculated similarly. The factor k/p_I is a common scaling factor for all terms. The international price [p_I] ensures correct units and a reasonable scale. The constant [k] is set to k = 1 in the model.

Because producers shift between markets based on shares, while consumers are assumed to buy the least expensive option, consumer prices can drop slightly below the international price if the local market is saturated, but they will not rise above the international price.

5.3 Feedstock prices

As with domestic fuel prices, feedstock prices are determined by an equilibrium-seeking algorithm, and the presentation uses a simplified notation. In the case of feedstocks, demand [$D(K_{\text{fuel}})$] is determined by the capital invested in fuel production [K_{fuel}] and non-bioenergy demand [$D_{\text{other}}(p)$]. A baseline trajectory for non-bioenergy demand for feedstocks is specified exogenously; otherwise, demand responds to changes in price relative to the previous time-step through an elasticity. Supply [$S(K_{\text{feedstock}}, p)$] is determined by the capital invested in feedstocks [$K_{\text{feedstocks}}$] and possibly also price [p], if it falls low enough that feedstock producers operate below their maximum level. Investments in fuel production [$I_{\text{fuel}}(p)$] and feedstock production [$I_{\text{feedstock}}(p)$] are each influenced by the feedstock price, [p]. The equation is then

$$\frac{dp}{dt} = bp\frac{D(K_{\text{fuel}})+D_{\text{other}}(p)-S(K_{\text{feedstock}},p)}{D(K_{\text{fuel}})+D_{\text{other}}(p)}, \tag{55}$$

where b relates excess demand to changes in price. The stock of capital changes in each sector due to investment and depreciation,

$$\frac{dK_{\text{fuel}}}{dt} = I_{\text{fuel}}(p) - \delta_{\text{fuel}}K_{\text{fuel}}, \tag{56a}$$

$$\frac{dK_{\text{feedstock}}}{dt} = I_{\text{feedstock}}(p) - \delta_{\text{feedstock}}K_{\text{feedstock}}. \tag{56b}$$

With these equations, prices adjust via differential rates of investment in fuel and feedstock operations, as well as the change in non-bioenergy feedstock demand.

Both Equation 56a and Equation 53 affect capital accumulation for fuel consumption. In the model, both the feedstock price and the biofuel price affect the attractiveness of biofuel production as an investment. To simplify the presentation of the algorithm, the combination of effects is not presented explicitly here.

5.4 Price adjustment coefficients and 'tâtonnement'

In equations 52 and 55, prices adjust when supply is not equal to demand, following

$$\frac{dp}{dt} = kp\frac{D(p)-S(p)}{D(p)}, \tag{57}$$

where k is the price adjustment coefficient. This is a version of the classical 'tâtonnement', or 'groping' process, described by Walras, in which prices are announced by sellers, buyers decide on their purchases on the basis of those prices, and then sellers subsequently adjust their prices based on their observations of the market (Walker 1987, Ferguson 1998). In contrast to the canonical disequilibrium model, in which the adjustment parameter has units of quantity per unit price, per unit time, Equation 57 has only a time scale, and the adjustment parameter k as units of inverse time.

In order to better interpret Equation 57 and to gain some understanding of reasonable values for k, we rewrite Equation 57 as

$$\frac{dp}{dt} = kpR(p), \tag{58}$$

where

$$R(p) \equiv \frac{D(p)-S(p)}{D(p)} = 1 - \frac{S(p)}{D(p)}. \tag{59}$$

At the equilibrium price [p^*], the ratio [$R(p)$] is equal to zero, and $S(p^*) = D(p^*)$. Suppose that near the equilibrium price, the price elasticity of demand is $-\alpha$, and the price elasticity of supply is β. Then, because supply and demand are equal at the equilibrium price, for prices near equilibrium,

$$R(p) \approx 1 - \left(\frac{p}{p^*}\right)^{\alpha+\beta}. \tag{60}$$

Setting the price equal to the equilibrium price plus a small gap, we have

$$\frac{dp}{dt} \approx kp^*R(p^*) + k\Delta pR(p^*) + kp^*\left.\frac{dR}{dp}\right|_{p=p^*}\Delta p. \tag{61}$$

Because $R(p^*) = 0$, this simplifies to

$$\frac{dp}{dt} \approx kp^*\left.\frac{dR}{dp}\right|_{p=p^*}\Delta p. \tag{62}$$

Taking the derivative of $R(p)$ with respect to p, using Equation 60, and substituting into Equation 62 gives

$$\frac{dp}{dt} \approx -k(\alpha+\beta)\Delta p, \tag{63}$$

so that, in a time-step [Δt], the price changes by an amount

$$\hat{\Delta p} \equiv \frac{dp}{dt}\Delta t \approx -(k\Delta t)(\alpha+\beta)\Delta p. \tag{64}$$

The direction of change is opposite that of Δp, because the tâtonnement process restores prices to equilibrium. To understand the value of k, we rearrange Equation 64 and take the absolute value, to give

$$k = \frac{1}{\alpha+\beta}\left|\frac{\hat{\Delta p}}{\Delta p}\right|\frac{1}{\Delta t}. \tag{65}$$

The ratio $|\hat{\Delta p}/\Delta p|$ is the size of the price step relative to the initial distance from the price at equilibrium. If the ratio is close to or greater than one, then price adjustments will tend to overshoot and prices will leap about their equilibrium value. If it is significantly less than one then the price will tend to converge smoothly towards its equilibrium. The sum $\alpha + \beta$ is the combined elasticity of demand and supply. Since it is in the denominator, for a fixed relative price step, the value of k when demand and supply are relatively elastic should be smaller than if demand and supply are relatively inelastic.

Demand and supply elasticities in the model are influenced by many factors, and differ in the short and long term due to lags in production. Moreover, the data needed to properly calibrate the model are lacking. Thus, we do not apply Equation 65 directly. Instead, in the model, we assign default values to the price adjustment coefficients that give reasonable behaviour, and then carry out sensitivity runs between half and twice the default value.

5.5 Wages and land price

Wages and land prices are important determinants of investment and profitability for biofuel and feedstock operations. If they are too high, then investments will not flow. Also, as wages rise over time, a profitable operation can become unprofitable.

Over time, average income (gross domestic product per capita) is expected to rise. Wages will also tend to rise with average income, but perhaps not at the same rate. This is captured in the model by having wages $[w]$ vary with average income $[y]$ in the following way:

$$w = w_0\left(\frac{y}{y_0}\right)^{\eta}, \tag{66}$$

where η is, for low-income jobs, typically less than one. If $\eta = 1$, then wages in the sector rise at the same rate as average income across the economy. If $\eta < 1$, then wages rise less quickly than for the economy as a whole.

The price of land $[p_N]$ is expected to rise as land becomes more scarce. This is captured in the model with the following formula:

$$p_N = p_{N0}\left[1 + \frac{1}{2}\left(\frac{A}{A_{\max}-A}\right)^3\right]. \tag{67}$$

With this equation, prices stay low until the area planted with feedstock gets close to the maximum, as shown in Figure 3. The price diverges as the maximum area is approached – the steeply rising price effectively shuts off investment at some point below the maximum, when the price rises to the point that further investment becomes unprofitable.

Within the model, each feedstock is assigned a maximum land area and a price, with one area specified in the case of no agroecological zoning and another area specified with agroecological zoning.

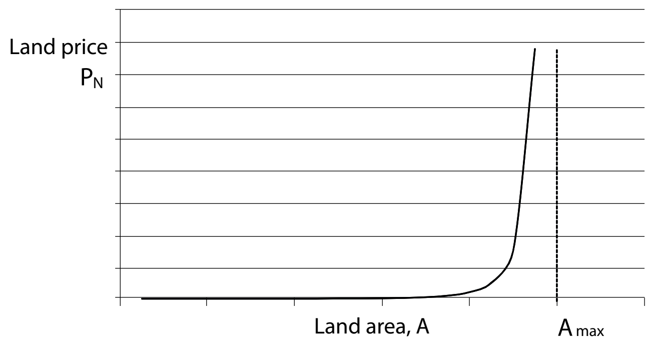

Figure 3. Land prices with changing area of feedstock

6. Risk and learning

In the model, risk is captured entirely in the expression for the expected return, copied here from Equation 16,

$$r_E = r_{\mathrm{rf}} + \beta(r_{\mathrm{ave}} - r_{\mathrm{rf}}) + \gamma r_{\mathrm{curr}} + \rho_{\mathrm{macro}} + \rho_{\mathrm{micro}} - \theta. \quad (68)$$

In this expression, the risk factors γ and ρ_{macro} can, in principle, be gathered from data. The systematic risk coefficient β can be calculated for many investments, but not for biofuel investments in most countries, as there are insufficient historical data to support the calculation. The micro term ρ_{micro} depends to some extent on subjective factors, and so it cannot be estimated from historical data; in practice, ρ_{micro} might be based on checklists, personal knowledge or expert opinion (Moosa 2002). The 'irrational optimism' term θ might be estimable from behavioural finance research (Pompian 2006), but in the model it plays the role of a scenario parameter or an adjustment parameter. For example, a scenario may explore irrational optimism over some particular biofuel. A positive value for θ can be applied in that scenario.

6.1 Systematic risk and currency risk

As explained in Section 3.3, the parameter β is a measure of the correlation between the returns from an investment and the market as a whole – the systematic risk. Similarly, the currency risk parameter γ represents how the value of the national currency correlates to a basket of currencies. The parameters β and γ are introduced in the same way that they might be reported in earnings reports or international tables. While data for biofuel investments are scarce, it is possible to estimate a range of values for β. This is discussed in Section 7.1.

6.2 Macropolitical and macroeconomic risk

The macro risk factor [ρ_{macro}] is estimated in the model using the country risk factors [R_{IHS}] from IHS Global Insight, which rates countries' risk on a scale from 1 (low risk) to 5 (high risk). To convert that value into a premium on the discount rate, the following transformation is applied,

$$\rho_{\mathrm{macro}} = \left(\frac{R_{\mathrm{IHS}} - 1 + \varepsilon}{5 - R_{\mathrm{IHS}} + \varepsilon}\right)^2 \hat{\rho}_{\mathrm{macro}}. \quad (69)$$

In Equation 69, ϵ is a small value that ensures that ρ_{macro} does not become undefined if the risk factor R_{IHS} is equal to five. The value $\hat{\rho}_{\mathrm{macro}}$ is the value of ρ_{macro} when $R_{\mathrm{IHS}} = 3$: that is, at medium levels of risk. Representative values for ρ_{macro} when $\epsilon = 0.01$ and $\hat{\rho}_{\mathrm{macro}} = 1\,\%$ are shown in Table 1 for selected countries using data from IHS Global Insight. As the table shows, the values begin to increase rapidly at higher risk levels.

Table 1. Representative values for country risk factors and macro contribution to discount rate

	R_{IHS}	ρ_{macro}
Sweden	1.33	0.01%
Japan	1.75	0.05%
Republic of Korea	2.06	0.13%
India	2.73	0.58%
Medium	*3.00*	*1.00%*
Ukraine	3.14	1.32%
Cameroon	3.53	2.95%
Tajikistan	3.89	6.70%
Republic of the Sudan	4.28	20.31%

ρ_{macro} = macro risk factor
R_{IHS} = country risk factor

6.3 Micropolitical and microeconomic risk

The remaining term ρ_{micro} is calculated in the model based on perceptions. It is calculated using a simple heuristic formula,

$$\rho_{\mathrm{micro}} = \hat{\rho}_{\mathrm{micro}} \prod_{i=1}^{N} (1 - \phi_i)^{b_i}, \quad (70)$$

where the φ_i are various factors that affect perceived risk, and the exponents b_i are weights. In the default setting for the model, the weights are all set equal to one. All of the factors take values from zero to one, and as they increase, risk goes down. The factor $\hat{\rho}_{\mathrm{micro}}$ is the value of ρ_{micro} when the level of risk is highest.

Separate sets of factors apply to feedstock production and fuel production. For feedstock production, the factors are

- political commitment (or political 'will');
- farmer knowledge; and
- security of tenure;

while for fuel production, the factors are

- political commitment; and
- domestic experience with the particular fuel processing technology.

Political commitment and security of tenure are scenario variables that are simply set as values between zero and one. Farmer knowledge and domestic experience are calculated using a 'learning' submodel that allows for the stock of farmer- and national-knowledge to grow over time.

6.4 Learning

In the learning submodel, learning takes place in the following way. For a learning community (for example, farmers or extension workers), there is a maximum level of knowledge they can attain, as determined by the global level of knowledge. The global level is set as an exogenous parameter, with a value of zero representing no information at all and a value of one representing thorough knowledge that supports routine operations and standardization. If the maximum level for the 'learning index' [$\lambda(t)$] is $\lambda_{max}(t)$, then the stock of knowledge (the learning index) changes over time as

$$\frac{d\lambda(t)}{dt} = \kappa P(t)(\lambda_{\max}(t) - \lambda(t)). \qquad (71)$$

In this equation, annual production is given as $P(t)$ The parameter κ sets the maximum rate of accumulation of knowledge. Learning is fast if there is a large gap between local and general knowledge, and it slows down as the community's knowledge approaches the maximum level, which can change over time.

For feedstocks, the model for farmer knowledge applies a nested version of Equation 71. First, knowledge of extension workers grows toward an exogenously specified global level. Second, smallholder knowledge approaches a weighted average of the global level and extension worker knowledge, depending on how effective extension services are (a user-specified policy variable). Farmers on estates are assumed to have the same level of knowledge (or to have access to the same knowledge) as extension agents.

For the biofuel processing sector, Equation 71 is applied directly, with global experience specified exogenously and domestic experience approaching the global level with cumulative production.

6.4.1 Learning curves

In Equation 71, learning only takes place if there is production, consistent with conventional models of industrial learning (Hall and Howell 1985). This is a consequence of the factor $P(t)$ before the expression in parentheses. The solutions to Equation 71 can be related to observations from studies of industrial learning. In the special case where $\lambda_{max}(t)$ is constant in time, Equation 71 can be solved explicitly to give

$$\lambda(t) = \lambda_{\max} - e^{-\kappa P_{\mathrm{cum}}(t)}(\lambda_{\max} - \lambda_0), \qquad (72)$$

where λ_0 is the initial value for $\lambda(t)$ and P_{cum} is cumulative (rather than annual) production. A sample curve is shown in Figure 4, where the learning index increases in an s-shaped fashion with cumulative production. This is the shape observed in learning curves within firms, where 'learning' is measured by worker productivity (Hall and Howell 1985). This pattern contrasts with the constant slope observed for 'experience curves', which plot the logarithm of unit cost against the logarithm of cumulative production within a sector, and are a conventional tool in business and management (de Wit *et al.* 2010). However, there is good reason to

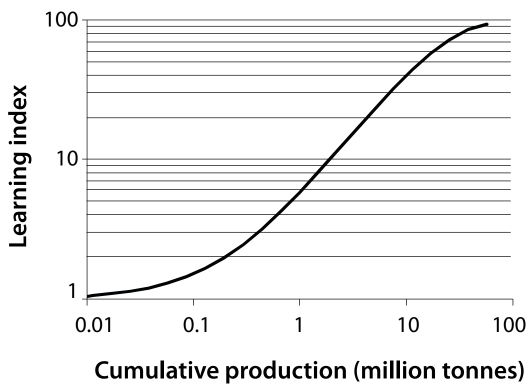

Figure 4. Learning vs. cumulative production for $f = 0$, $\kappa = 5\%$/Mt/year

think that the linear slope of experience curves has more to do with the benefits of increasing scale and other factors, rather than learning (Hall and Howell 1985). As scale economies are explicitly taken into account in the NBIM, it is reasonable that the learning curve described by equations 71 and 72 follow the s-shaped pattern observed in studies of industrial learning. Nevertheless, we add a caution that industrial learning curves are based on the experience of individual plants, whereas equations 71 and 72 are applied at sector level.

6.4.2 Learning and yields

Yields in the model increase as farmers learn. Yields can increase by a maximum ratio y_{max} relative to the initial value, an increase which is achieved only when the learning factor $\lambda = 1$. The ratio $y(\lambda)$ as a function of the learning level is given as

$$y(\lambda) = \frac{1}{1-\lambda_0}\left[1 - \lambda_0 y_{\max} + (y_{\max} - 1)\lambda\right]. \quad (73)$$

With this equation, when λ is at its initial value, $\lambda = \lambda_0$, and $y(\lambda_0) = 1$, as expected. When λ is at its maximum value of $\lambda = 1$, $y(1) = y_{max}$, again as expected. Between the two extremes the yield increases linearly with the level of knowledge.

7. Parameter uncertainty

Scenario models are useful tools for exploring options under uncertainty. The most important types of uncertainty in a scenario are the highly uncertain and high-impact external factors that can significantly affect the success of a policy. However, ordinary parameter uncertainty is also present. The NBIM is particularly afflicted by parameter uncertainty, as it simulates a poorly understood (although well studied) phenomenon, investor decision making. To communicate this uncertainty to the model user, the model is run in a 'sensitivity mode', in which parameter values are sampled from statistical distributions. Typically, the literature provides plausible minimum, maximum and nominal values, but not a statistical distribution. For simplicity, we sample parameters from triangular distributions, as illustrated in Figure 5. The nominal value (that is, the model default value) is also the mode of distribution. The probability is zero below the minimum and above the maximum, and otherwise the distribution is linear.

7.1 Investment betas

The model simulates two distinct but connected markets: that for biofuel feedstocks and that for biofuels. To the extent that biofuel feedstock

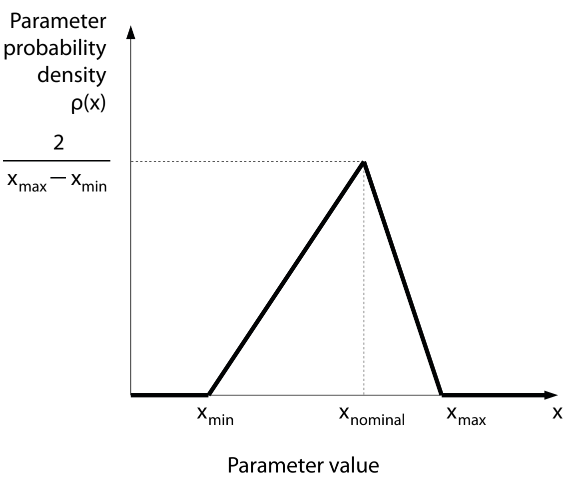

Figure 5. Triangular distribution for uncertain parameters

markets behave like the market for farmland, β can be expected to be relatively low, around 0.2 (Barry 1980, Canavari *et al.* 2002). However, βs for agribusiness firms have been found to be close to 1.0 (Wilson and Featherstone 2006, Tepe 2010). Biofuel markets are likely to be sensitive to changes in the market as a whole, since they are linked to energy markets, so β is expected to be relatively large. While studies of biofuel markets using the ICAPM are rare (for example, Baker *et al.* [2008] applies ICAPM to the biofuel market, but does not report estimates for β), renewable energy markets have been studied. In Sadorsky (2012), βs for renewable energy companies were found to be quite high, with benchmark estimates close to 2.0, but rising for some models close to 4.0. In the default settings for the model, β for feedstocks takes a value of 0.50, while in sensitivity runs it is assumed to follow a triangular distribution with a minimum of 0.25, a maximum of 1.50, and a mode of 0.50. The β for fuels defaults to 2.0, and in sensitivity runs follows a triangular distribution with a minimum of 0.75, a maximum of 3.00, and a mode of 2.00.

7.2 Investment uncertainty (entropy weight)

The weight [φ] given to the entropy term in the investment objective function of Equation 19 is a tuning parameter for the model. In principle it can be estimated by fitting the model to observed data. However, few data are available with which to calibrate the model, and so it is represented as an uncertain parameter. The model user can set the minimum, maximum and nominal values. By default, for international investors, the values are set at 0.10 (minimum), 0.20 (nominal) and 0.30 (maximum). For domestic investors, the default values are 0.05 (minimum), 0.10 (nominal) and 0.15 (maximum). These values reflect an assumption that domestic investors are comparatively knowledgeable about local investment opportunities, and so the distribution of investments shows less uncertainty and less spread than for foreign investors.

7.3 Fuel and feedstock price adjustment coefficients

The price adjustment coefficients *a* and *b* for fuels and feedstocks determine the rate of price adjustment when supply and demand are out of equilibrium, as given in equations 52 and 55. As explained in Section 5.4, the parameters are assigned values that give apparently reasonable model behaviour. The user can adjust these separately for each fuel and feedstock. By default, they are set to 0.04/year for feedstocks and 0.50/year for fuels. As the parameters are quite uncertain, by default they are set to vary between half and twice their default values, that is, 0.02–0.08/year for feedstocks and 0.25–1.00/year for fuels.

7.4 Crop yields

In the model it is assumed that investment decisions are made on the basis of anticipated yields – that is, on the basis of the nominal value for the yields of each crop. However, actual production may differ from the nominal value by a factor with a nominal value of 1.0, and a user-defined minimum and maximum value. Users can assign a larger range for crops whose yields are less well known than for better known crops.

8. Comments

The NBIM is a non-equilibrium dynamic model that features ‘boom and bust’ cycles, as actually experienced in biofuel feedstock and other cash crop operations. The model is intended to be used in an interactive setting, complimented by a narrative scenario process.

As with any model, the outputs are only as good as the inputs and the model assumptions. Simulation models, which attempt to anticipate human behaviour, require particular caution. The intended use of the model is to quickly try out a variety of options in an environment where any surprising outcomes can be investigated in detail. Policy analysts and policymakers may eliminate some policy options after such an exercise, if they seem to provide limited benefits, while choosing other, more promising options for further investigation.

9. References

Adams, S. 2009 Foreign direct investment, domestic investment, and economic growth in sub-Saharan Africa. Journal of Policy Modeling 31: 939-949.

Ahlquist, J. 2006 Economic policy, institutions, and capital flows: Portfolio and direct investment flows in developing countries. International Studies Quarterly 50: 681-704.

Akinkugbe, Oluyele. 2003 Flow of Foreign Direct Investment to Hitherto Neglected Developing Countries. Discussion Paper. Helsinki: UNU/WIDER. http://www.wider.unu.edu/publications/working-papers/discussion-papers/2003/en_GB/dp2003-02/_files/78091724471534368/default/dp2003-02.pdf.

Asiedu, E. 2002 On the determinants of foreign direct investment to developing countries: Is Africa different? World Development 30: 107-119.

Asmussen, C.G., Benito, G.R. and Petersen, B. 2009 Organizing foreign market activities: From entry mode choice to configuration decisions. International Business Review 18: 145-155.

Baker, M.L., Hayes, D.J. and Babcock, B.A. 2008 Crop-based biofuel production under acreage constraints and uncertainty. Center for Agricultural and Rural Development, Iowa State University, USA.

Barry, P.J. 1980 Capital asset pricing and farm real estate. American Journal of Agricultural Economics 62: 549-553.

Blonigen, B.A., Davies, R.B., Waddell, G.R. and Naughton, H.T. 2007 FDI in space: Spatial autoregressive relationships in foreign direct investment. European Economic Review 51: 1303-1325.

Busse, M. and Hefeker, C. 2007 Political risk, institutions and foreign direct investment. European Journal of Political Economy 23: 397-415.

Canavari, M., Caggiati, P. and Easter, K.W. 2002 Economic studies on food, agriculture, and the environment, New York, Kluwer Academic/Plenum.

Carlesi, L., Verster, B. and Wenger, F. 2007 The new dynamics of managing the corporate portfolio. McKinsey on Finance 23: 1-8.

Chaudhuri, S. and Banerjee, D. 2010 FDI in agricultural land, welfare and unemployment in a developing economy. Research in Economics 64: 229-239.

Colman, D. and Young, T. 1989 Principles of agricultural economics: Markets and prices in less developed countries. Cambridge University Press, Cambridge, UK.

Dahlquist, M. and Robertsson, G. 2001 Direct foreign ownership, institutional investors, and firm characteristics. Journal of Financial Economics 59: 413-440.

de Wit, M., Junginger, M., Lensink, S., Londo, M. and Faaij, A. 2010 Competition between biofuels: Modeling technological learning and cost reductions over time. Biomass and Bioenergy 34: 203-217.

Dippenaar, A. 2009 What drives large South African corporations to invest in sub-Saharan Africa? CEO's perspectives and implications for FDI policies. Natural Resources Forum 33: 199-210.

Ferguson, B.S. 1998 Introduction to dynamic economic models. Manchester University Press, Manchester, UK.

Graham, J.R. and Harvey, C.R 2001 The theory and practice of corporate finance: Evidence from the field. Journal of Financial Economics 60: 187-243.

Hall, G. and Howell, S. 1985 The experience curve from the economist's perspective. Strategic Management Journal 6: 197-212.

Hallegatte, S., Ghil, M., Dumas, P. and Hourcade, J. 2008 Business cycles, bifurcations and chaos in a neo-classical model with investment dynamics. Journal of Economic Behaviour and Organization 67: 57-77.

Hennart, J. and Park, Y. 1993 Greenfield vs. acquisition: The strategy of Japanese investors in the United States. Management Science 39: 1054-1070.

Hosier, R.H. 1993 Urban energy systems in Tanzania: A tale of three cities. Energy Policy 21: 510-523.

Hosier, R.H. 2004 Energy ladder in developing nations. *In:* Encyclopedia of energy, 423-435, Elsevier, New York, NY, USA.

Jenkins, R and Edwards, C. 2006 The economic impacts of China and India on sub-Saharan Africa: Trends and prospects. Journal of Asian Economics 17: 207-225.

Jinjarak, Y. 2007 Foreign direct investment and macroeconomic risk. Journal of Comparative Economics 35: 509-519.

Kennedy, P. 2003 A guide to econometrics. MIT Press, Cambridge, MA, USA.

Kinda, T. 2010 Investment climate and FDI in developing countries: Firm-level evidence. World Development 38: 498-513.

Klier, D.O. 2009 Managing diversified portfolios: What multi-business firms can learn from private equity. Physica-Verlag, Heidelberg, Germany.

Kogut, B. and Nath, R. 1988 The effect of national culture on the choice of entry mode. Journal of International Business Studies 19: 411-432.

Li, J. and Rugman, A.M. 2007 Real options and the theory of foreign direct investment. International Business Review 16: 687-712.

Li. Q. and Sherali, H.D. 2003 An approach for analyzing foreign direct investment projects with application to China's Tumen River Area development. Computers and Operations Research 30: 1467-1485.

Li, S. and Filer, L. 2007 The effects of the governance environment on the choice of investment mode and the strategic implications. Journal of World Business 42: 80-98.

Lim, S. 2008 How investment promotion affects attracting foreign direct investment: Analytical argument and empirical analyses. International Business Review 17: 39-53.

Moosa, I.A. 2002 Foreign direct investment: Theory, evidence, and practice. Palgrave, Houndmills, UK.

Nocke, V. and Yeaple, S. 2007 Cross-border mergers and acquisitions vs. greenfield foreign direct investment: The role of firm heterogeneity. Journal of International Economics 72: 336-365.

Pompian, M.M. 2006 Behavioral finance and wealth management: How to build optimal portfolios that account for investor biases. Wiley, Hoboken, NJ, USA.

Quandt, R.E. 1988 The econometrics of disequilibrium. Blackwell, New York, NY, USA.

Sadorsky, P. 2012 Modeling renewable energy company risk. Energy Policy 40: 39-48.

Sethi, D., Guisinger, S., Ford, D.L. and Phelan, S.E. 2002 Seeking greener pastures: A theoretical and empirical investigation into the changing trend of foreign direct investment flows in response to institutional and strategic factors. International Business Review 11: 685-705.

Solnik, B.H. 2000 International investments. Addison-Wesley, Reading, MA, USA,.

Tepe, F.S. 2010 Biofuel policy and stock price in imperfectly competitive markets. MS Thesis, Iowa State University, Ames, IA, USA.

Walker, D.A. 1987 Walras's theories of tatonnement. The Journal of Political Economy 95: 758-774.

White, C. and Fan, M. 2006 Risk and foreign direct investment. Palgrave MacMillan, Houndmills, UK.

Wilson, C., and Featherstone, A., 2006 Adjusting the CAPM for threshold effects: An application to food and agribusiness stocks. Working Paper 06-08, Purdue University, College of Agriculture, Department of Agricultural Economics, West Lafayette, IN, USA.

Annex 1. Policy instruments, drivers, critical uncertainties and trends

The policy instruments are as follows:

- Environmental impact assessment (self-reported environmental impact statement with and without monitoring);
- tax incentives for foreign direct investment (FDI);
- percentage of domestic ownership;
- mandatory blend ratios;
- priority sectors and free trade zones;
- agroecological zoning (suitability);
- minimum wages;
- market-based application of sustainability standards;
- regulations on land allocation;
- extension and credit services to smallholders;
- support to negotiation (terms of land lease);
- repatriation of profits;
- minimum percentage of smallholder produced biofuel;
- legislating around sustainability standards;
- tax incentives for FDI with conditionality

The national-level indicators are as follows:

- percentage of liquid fuel produced domestically;
- volume of oil imports;
- value of energy imports as a percentage of gross domestic product;
- kWh of co-generated electricity;
- proportion of household energy consumption from biofuels;
- volume of national charcoal consumption;
- dollars saved on imports of oil;
- value of biofuel exports;
- percentage of domestic shareholding in biofuel companies;
- proportion of feedstock processed domestically;
- percentage of domestic biofuel production that is consumed nationally;
- tax revenue at pump;
- company tax (tax revenue and net profits);
- tax revenue from salaried employees;
- import taxes;
- export taxes;
- percentage of profits repatriated abroad;
- net present benefit to the economy;
- net cost;
- reduced deforestation due to bioenergy expansion;
- percentage of liquid biofuels produced by smallholders;
- total jobs created in the biofuel sector.

Critical uncertainties include the following:

- risk tolerance;
- potential to domesticate FDI flows;
- World Trade Organization rules on biofuels;
- suitability of auto fleet;
- prices (fossil fuel, oil as food vs. biodiesel, variability);
- productivity of food crops;
- political will;
- land tenure;
- climate risk;
- availability of financial resources to advance biofuels production;
- regional coordination on biofuels production.

Trends include the following:

- demands from EU standards;
- local technology and innovations;
- knowledge of extension workers;
- rights of chiefs to allocate land;
- domestic demand;
- level of knowledge about biofuel feedstocks;
- suitability of auto fleet;
- economic orientation (export-oriented vs. import substitution);
- value-added potential of agro-processing industries;
- land suitability and availability;
- international experience with relevant technologies and policies;
- experience of farmers (current and over time) with cash crop production;
- strategic plan to drive the biofuels industry;
- undermining of price by neighbouring countries;
- competition with fossil fuels;
- environmental concerns (nongovernmental organisations).

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