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Energy imports and manufacturing exports with successive oligopolies and storage

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ABSTRACT

Many industrial countries run a "business model" that is based on oligopolistic export industries which strongly depend on energy imports. This paper uses an analytically tractable general equilibrium model of international trade with successive oligopolies and storage to analyze optimum trade and industrial policies for such countries. There can be over-investment in storage for strategic reasons. Despite double marginalization, there is a non-zero optimum level of market concentration for the domestic industry. The optimum import tariff is most likely positive. Subsidies to storage and reduced use of long term contracts usually raise domestic welfare.

1. Introduction

That many countries depend on imported energy is a natural consequence of the geographical distribution of raw materials. More remarkably, a subset of these countries specialize in the production of energy-intensive manufacturing exports. "Germany's business model" (Fuest, 2022) is a clear case in point, as became apparent with the drying up of energy imports from Russia after the invasion of Ukraine (see, e.g., Burda, 2022; Fuest, 2022, 2023). Fig. 1 illustrates that other countries run a similar "business model". The diagram plots energy self-sufficiency against the percentage share of manufactures exports (as a proxy for energy-intensive exports) in total merchandise exports for the twenty-five countries with the highest value of the latter variable in 2019 (dismissing countries with merchandise exports worth less than one billion US dollars; country codes in Appendix B). The sizes of the circles indicate the volumes of merchandise trade.[1] The figure shows that several, predominantly European and East Asian, countries specialize in energy-intensive exports in spite of lack of domestic resources. Germany's energy self-sufficiency (35.4 percent) is somewhat below the unweighted mean among these countries (43.0 percent). The values for the two next-biggest EU economies are 53.8 percent (France) and 23.1 percent (Italy). Values below 20 percent are reported for major East Asian economies (11.9 percent for Japan, 17.8 percent for South Korea, 0.0 percent for Hong Kong).

This paper analyzes the effects of competition, storage, trade policy, and industrial policy in an analytically tractable general equilibrium model of international trade comprised of a resource-abundant country and an industrial country that depends on energy imports. We consider two variants of the model. In the ECG ("energy as a consumption good") model, imported energy is distributed to consumers by domestic wholesalers. In the ERMI ("energy as a raw material for industries") model, imported energy is an input in the production of manufacturing exports.[2] In both model variants trade in energy gives rise to successive oligopolies. This reflects the observations that energy production in resource-abundant countries is dominated by large, often state-owned, companies (see Talus, 2014), that wholesale energy markets are often characterized by imperfect competition, especially in Europe (see Talus, 2014), and that export markets for industrial goods are also often

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[1] The data on exports are from the World Bank Open Data website https://data.worldbank.org/indicator/TX.VAL.MANF.ZS.UN (accessed 22 December 2023), the data on energy self-sufficiency from the United Nations Energy Statistics Pocketbook 2022 https://unstats.un.org/unsd/energystats/pubs/documents/2022pb-web.pdf (accessed 22 December 2023).

[2] Paraphrasing Burda's (2022) observation that "the 'German model' is …steeped in chemicals, metallurgy, and pharmaceuticals, all particularly energy- or gas-intensive sectors. …natural gas is essential for the heating of households as well as a raw material for the chemical and pharmaceutical industries".

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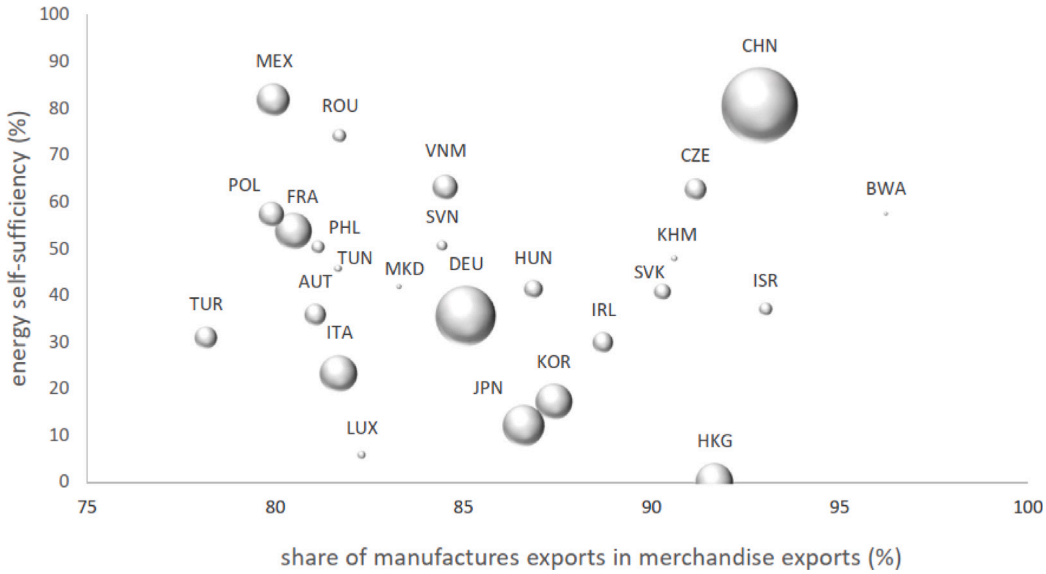

Fig. 1. Energy self-sufficiency of the twenty-five countries with the highest share of manufactures exports in total merchandise exports.

highly concentrated.[3] Accordingly, at the core of our model is the successive oligopolies model pioneered by Greenhut and Ohta (1979) and Salinger (1988), and others.

Our model contributes to five different strands of literature, viz., successive oligopolies in energy markets, strategic storage, storage and welfare, trade policy with imperfect competition, and long term contracting in energy markets. It provides a coherent framework that reaffirms several existing results and adds new ones.

Successive oligopolies in energy markets: Boots et al. (2004), Holz et al. (2008), and Abada et al. (2013), among others, use numerical models with successive oligopolies to analyze European energy markets. Holz et al. (2008) emphasize the welfare gains, due to weaker double marginalization, of enforcing competition. Boots et al. (2004) add that, as concentration is higher in the upstream market, pro-competitive policies are more effective there than in the downstream segment. The ECG variant of our model confirms that there are welfare gains from pro-competitive policies for the resource-poor industrial country. A country has more to gain, however, from a decrease in market concentration abroad than at home even if concentration is lower abroad than at home, because the reduction in double marginalization does not come at the expense of lower domestic profit income. In the ERMI variant of our model, for each of the two countries there is a finite optimum number of domestic oligopolists. That is, despite stronger double marginalization, a certain degree of concentration of the domestic industry is beneficial to domestic welfare.

Strategic storage: Building on earlier work by Arvan (1985), Durand-Viel (2007) incorporates storage into the successive oligopolies model in a partial equilibrium setting with one producer at the first stage and two producers at the second stage. Assuming that stored energy cannot be resold in spot markets, she demonstrates the possible existence of asymmetric equilibria, in which only one of the ex ante identical second-stage duopolists engages in storage. This is the paper most closely related to ours: our results on equilibrium prices yield Durand-Viel's (2007) results for symmetric equilibria as special cases with an upstream monopoly and a downstream duopoly. Other industrial organization papers on storage in energy markets with imperfect competition include Saloner (1987), Pal (1991), and Chaton et al. (2008). In the model of Saloner (1987) and Pal (1991) output is produced at two dates and sold at a single date in their model. Production is possibly positive at the earlier date, even though marginal cost is higher than at the latter date. Baranes et al. (2014) show that gas companies may store more gas than they intend to sell to consumers for strategic reasons. Our model gives rise to a notion of over-investment in storage that is similar to Pal's (1991): storage can be positive even though the current price exceeds the discounted expected future price, i.e., the net present value of storage (*excluding cost*) is negative holding prices constant. Negative income generated by energy arbitrage (including cost) occurs for a wide range of parameterizations of the model.

Storage and welfare: Sioshansi (2010, 2014) and Schill and Kemfert (2011), among others, analyze the welfare effects of access to storage facilities. Storage yields welfare gains in perfectly competitive markets, but may cause welfare losses in imperfectly competitive environments. Our model shows that perfect competition *abroad* is sufficient for welfare gains due to storage at home. Firms' and consumers' interests are aligned in this case, and the optimum subsidy to storage is zero. With imperfect competition in energy production, domestic utility can be lower with storage than without storage. Usually, however, the optimum subsidy to storage is positive.

Trade policy in vertically related markets: A branch of the literature on trade policy in imperfectly competitive markets, initiated by Spencer and Jones (1991), focuses on vertically related markets. There exist market structures in which positive import tariffs on imported intermediate inputs (such as energy) "backfire": in Ishikawa and Lee (1997), for instance, a positive tariff on an intermediate good can induce entry of foreign firms in the domestic final goods market, thereby potentially reducing domestic profits. Our model with a foreign upstream oligopoly and a domestic downstream oligopoly adds a novel case to this branch of the literature. We show that, as in models with perfect competition, the optimum tariff the industrial country levies on its energy imports is usually positive. A sufficient condition is that market concentration is higher abroad than at home.

Long term contracts in energy markets: A policy-oriented branch of the literature discusses the relative benefits of long term contracts versus spot trade in energy markets (e.g., Talus, 2014; Abada et al., 2019). Long term contracts reduce the riskiness of investments in production facilities and the risk of price hikes for users. While our model does not incorporate capacity choices by energy producers, it sheds light on how the use of long term contracts affects competition between energy producers and users: in an equilibrium with storage, long term contracts

[3] Import dependence and market structure are similar in markets for non-energy commodities such as cobalt, boron, silicon, graphite, magnesium, lithium, niobium, rare earths, or titanium. For the sake of concreteness, we call the traded commodity energy throughout.

eliminate the strategic impact of storage on future prices and lead to higher import prices and lower domestic utility.

The paper is organized as follows. Section 2 presents the model. Sections 3 and 4 characterize equilibrium and its welfare properties. Sections 5–8 analyze trade policy, competition policy, subsidies to storage, and long term contracts. Section 9 concludes. Proofs are collected in Appendix A. A list of all symbols used is in Appendix B.

2. Model

The world economy is made up of two countries, home and foreign. Energy is produced in the foreign country and imported by the home country. The model allows for two alternative interpretations. Under the first interpretation the home country produces an industrial good using imported energy as an intermediate input. We call this the ERMI (“energy as a raw material for industries”) model. Alternatively, domestic wholesalers distribute imported energy to consumers. We call this model the ECG (“energy as a consumption good”) model. Under either interpretation, there are successive oligopolies: there are finite numbers of energy producers and of domestic firms (i.e., industrial goods producers or energy wholesalers), which compete in quantities. There are two dates, $t = 1, 2$, and both demand and supply shocks at date 2. The energy price is high, in expectation, at date 2. One interpretation is seasonal fluctuations (with date 1 as spring/summer and date 2 as fall/winter). An alternative interpretation, in particular with regard to long-term contracts, is a world with a long-term upward trend in energy prices. Domestic producers can store imported energy from date 1 to date 2, at a cost. Energy, goods, and financial capital are traded internationally.

The economy is populated by I (>0) domestic and I' (>0) foreign consumers, indexed i. Labor is the only primary factor of production. Each consumer, at home and abroad, inelastically supplies one unit of labor at each date in her country of residence. Energy is produced in the foreign country, at constant marginal cost c_t ($t = 1, 2$) in terms of labor. There are energy supply shocks: c_2 (>0) is a random variable with mean $\bar{c}_2$. Date-1 marginal cost c_1 (>0) is a constant. In the ERMI model, there are two goods. One good, called the consumption good, is produced using labor only in both countries. The amount of labor required for one unit of output is unity in the home country and $1/\omega$ (>1) abroad. The other good, called the industrial good, can only be produced in the home country, using labor and energy. The production technology is fixed coefficients (as, e.g., in Salinger, 1988, p. 347): one unit of energy and a_t units of labor yield one unit of the industrial good at date t ($= 1, 2$). a_2 (≥ 0) is random with mean $\bar{a}_2$. a_1 (≥ 0) is a constant. In the ECG model, domestic firms are wholesalers, which distribute energy to domestic consumers (cf., e.g., Greenhut and Ohta, 1979). Ignoring labor input in wholesaling, one can set $a_t = 0$ ($t = 1, 2$) in this case.

Let y_{it} denote the quantity of the consumption good i consumes at t, and let e_{it} denote her consumption of the industrial good (in the ERMI model) or energy (in the ECG model). Her date-t utility

$$u_{it} = y_{it} + \theta_i \left(\alpha_t e_{it} - \frac{1}{2} e_{it}^2 \right)$$

is quasi-linear. Linearity of utility in a good that is produced using labor only is the crucial assumption that allows for analytical welfare results, a property commonly exploited in international economics (see Feenstra, 2016, Ch. 8). $\theta_i = 1$ for domestic consumers. α_t (>0) determines their marginal utility of the industrial good (in the ERMI model) or of energy (in the ECG model) at t. There are demand shocks: α_2 is a random variable with positive support and mean $\bar{\alpha}_2$. α_1 is a constant. For foreign consumers, θ_i is in $\{0, 1\}$, where $\theta_i = 0$ in the ECG model, as $\theta_i > 0$ would mean that the foreign country exports energy only to repurchase it at a markup from domestic wholesalers. i's intertemporal utility is $u_{i1} + \beta u_{i2}$, where β (>0) is her discount factor.

Market structure is as in the literature on successive oligopolies, initiated by Greenhut and Ohta (1979). There are K (≥ 1) foreign energy producers, indexed $k = 1, \ldots, K$, owned by the foreign consumers (with uniform ownership shares). Similarly, there are J (≥ 1) domestic producers of the industrial good (in the ERMI model) or energy wholesalers (in the ECG model), indexed $j = 1, \ldots, J$, owned by domestic consumers (with uniform ownership shares).

Following Arvan (1985) and Durand-Viel (2007), domestic firm j can store energy between dates 1 and 2. Storing s_j (≥ 0) units of energy costs $\eta s_j^\gamma / \gamma$ units of labor and $\delta s_j^\gamma / \gamma$ units of energy, where $\eta \geq 0$ and $\delta \geq 0$, with one inequality strict, and $\gamma \in \{1, 2\}$. $\gamma = 1$ is the conventional case of constant marginal cost of storage, whereas $\gamma = 2$ implies increasing marginal cost of storage. Allowing for strict convexity of the cost of storage is necessary in order to ensure existence of equilibrium when the energy market is perfectly competitive (i.e., $K \to \infty$).[4] Contrary to Arvan (1985) and Durand-Viel (2007), domestic producers can resell stored energy to competitors in the date-2 spot market, which rules out asymmetric equilibria in which only one of the ex ante identical second-stage duopolists engages in storage.

3. Equilibrium

At both dates, let the consumption good be the numeraire. The markets for labor and the consumption good are perfectly competitive. As a result, the wage rate is unity at home and ω (<1) abroad at both dates. There is a perfectly competitive market for a safe asset, which is in zero net supply. The safe interest rate is denoted r. The subsequent formulas are interpreted using the ERMI version of the model. They apply without any modification to the ECG model.

There is spot trade in energy and industrial goods. The import price of energy and the price of the industrial good at date t are denoted q_t and p_t, respectively ($t = 1, 2$). Let π_{jt} and ψ_{kt} denote industrial goods producer j's and energy producer k's date-t profit, respectively. Producers choose their outputs so as to maximize the expected present value of their profits (i.e., $\pi_{j1} + \mathrm{E}\pi_{j2}/(1 + r)$ and $\psi_{k1} + \mathrm{E}\psi_{k2}/(1 + r)$, respectively). At each date t, industrial goods producers take the import price q_t resulting from energy producers' output choices as given (cf., e.g., Salinger, 1988).[5]

To set the stage for the analysis of trade policy in Section 5, we incorporate exogenous specific tariffs τ_t on domestic energy imports at date t ($t = 1, 2$). A negative tariff is an import subsidy. Throughout, we assume

$$\alpha_1 > \omega c_1 + a_1 + \tau_1, \ \ \bar{\alpha}_2 > \omega \bar{c}_2 + \bar{a}_2 + \tau_2, \tag{1}$$

which ensures that firms have incentives to sell positive amounts of the industrial good. The revenue generated by the tariffs is distributed via lump-sum payments to domestic consumers (the cost of a negative tariff is covered by a lump-sum tax).

Equilibrium is found recursively: agents take into account the impact of their date-1 actions on their date-2 objectives.

[4] For natural gas, it follows from the gas laws of thermodynamics that the marginal cost in terms of energy used rises with the amount of gas stored. According to the ideal gas law, the energy needed to compress n moles of a gas from volume V to V' ($<V$) at constant temperature is proportional to $n \log(V'/V)$. Let V be the given volume of the caverns operated by producer j and $V' = s_j$ the volume of the uncompressed gas she stores. As n is proportional to s_j, the energy needed for compression is proportional to $s_j \log(s_j/V)$. As

$$\frac{d}{ds_j} \left[s_j \log \left(\frac{s_j}{V} \right) \right] = 1 + \log \left(\frac{s_j}{V} \right),$$

the marginal cost of storage in terms of energy is an increasing function of the amount of storage. Under current techniques, only small amounts of the energy released when the gas re-expands after storage can be used.

[5] Ignoring storage, the subsequent results on oligopoly prices are the special case of Salinger (1988, Section III), with no integrated firms. Setting $I + \theta I' = 1$, $c_1 = c_2 = a_1 = a_2 = 0$, $\beta = 1$, $K = 1$, $J = 2$, $\gamma = 1$, and $\delta = 0$ yields Durand-Viel's (2007) results for the case of symmetric equilibria.

Date 2:

At date 2, consumer i chooses e_{i2} so as to maximize u_{i2}. Her demand is $e_{i2} = \alpha_2 - p_2$ if $\theta_i = 1$ and $e_{i2} = 0$ if $\theta_i = 0$ (see Appendix A.1). Let $E_{it} = \sum_i e_{it}$ $(t = 1, 2)$, and let $\theta = 1$ if $\theta_i = 1$ and $\theta = 0$ if $\theta_i = 0$ for foreign consumers. Then the inverse market demand for the industrial good is

$$p_2 = \alpha_2 - \frac{E_2}{I + \theta I'}. \tag{2}$$

Given the fixed coefficients technology, total energy input in the production of the industrial good is also E_2.

Industrial goods producer j chooses her output x_{j2} so as to maximize profit π_{j2}, given the amount stored at the preceding date s_j, the energy price q_2, and the demand function (2). We assume $s_j \le x_{j2}$ for all realizations of the shocks, so that domestic firms buy a positive amount of energy in the date-2 spot market. The necessary condition for profit maximization then gives p_2 as a weighted mean of unit cost $q_2 + a_2 + \tau_2$ and the demand shock α_2:

$$p_2 = \frac{J(q_2 + a_2 + \tau_2) + \alpha_2}{J + 1} \tag{3}$$

(see Appendix A.2).

Energy producers k maximize ψ_{k2}. This gives the date-2 energy price q_2 as a decreasing function of the quantities of energy stored by domestic firms s_j:

$$q_2 = \frac{K\omega c_2 + \alpha_2 - (a_2 + \tau_2) - \frac{J+1}{(I+\theta I')J}\sum_{j=1}^{J} s_j}{K + 1} \tag{4}$$

(see Appendix A.3). Assuming symmetry (i.e., $s_j = s$), the condition $s_j \le x_{j2}$ holds exactly if

$$s \le \frac{I + \theta I'}{J + 1}[\alpha_2 - (\omega c_2 + a_2 + \tau_2)] \tag{5}$$

(see Appendix A.3). It holds for all realizations of α_2, c_2, and a_2 if it holds for the lower bound of the support of $\alpha_2 - (\omega c_2 + a_2)$. For instance, let $\alpha_2 - (\omega c_2 + a_2)$ be equal to $\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2) - \sigma$ and $\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2) + \sigma$ with probability one-half each, where $\sigma^2 = \mathrm{var}(\alpha_2 - (\omega c_2 + a_2))$. Then (5) is satisfied with certainty if

$$s \le \frac{I + \theta I'}{J + 1}[\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2 + \tau_2) - \sigma]. \tag{6}$$

As

$$q_2 \ge \mathrm{E}q_2 - \frac{\sigma}{K + 1} + \omega(c_2 - \bar{c}_2)$$

in this binary example, q_2 is positive with probability one if $\mathrm{E}q_2 > \sigma/(K+1)$ and the lower bound of the support of c_2 is sufficiently close to $\bar{c}_2$.

Date 1:

At date 1, consumers choose consumption and savings so as to maximize $u_{i1} + \beta \mathrm{E} u_{i2}$. Optimum savings implies that the market discount factor is equal to consumers' subjective discount factor: $1/(1 + r) = \beta$. Analogously to (2), total energy demand obeys $p_1 = \alpha_1 - E_1/(I + \theta I')$ (see Appendices A.4 and A.6).

Industrial goods producers choose sales x_{j1} and storage s_j so as to maximize $\pi_{j1} + \beta \mathrm{E} \pi_{j2}$, given the energy price q_1 and consumers' demand. Analogously to (3),

$$p_1 = \frac{J(q_1 + a_1 + \tau_1) + \alpha_1}{J + 1} \tag{7}$$

(see Appendices A.5 and A.7). The condition for optimum storage s_j is

$$\begin{aligned} &\beta\left[\frac{K\omega \bar{c}_2 + \bar{\alpha}_2 - (\bar{a}_2 + \tau_2) - \frac{J+1}{(I+\theta I')J}\sum_{j'=1}^{J} s_{j'}}{K + 1} + \tau_2\right] \\ &-(q_1 + \tau_1) - \left[\eta + \delta(q_1 + \tau_1)\right] s_j^{\gamma - 1} - \beta\frac{J + 1}{(I + \theta I')J(K + 1)} s_j \\ &+\beta\frac{2}{J(K + 1)^2}\left\{\frac{K}{J + 1}[\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2 + \tau_2)] + \frac{1}{(I + \theta I')J}\sum_{j'=1}^{J} s_{j'}\right\} \le 0. \end{aligned} \tag{8}$$

with equality if $s_j > 0$ (see Appendix A.7). The left-hand side of (8) is the marginal profit of storage. The first three terms are the difference between the marginal revenue and the marginal cost of storage *holding prices constant*: the first term is the present value of a unit of energy stored $\beta(\mathrm{E}q_2 + \tau_2)$ (cf. (4)), the second term is the price paid for each unit of energy stored, and the third term is the marginal wage and energy cost of storage. The other two terms on the left-hand side capture the *strategic effects* of storage. From (4), the decrease in date-2 energy demand due to additional storage reduces q_2 and $\mathrm{E}q_2$. Thus, as pointed out by Durand-Viel (2007) and Baranes et al. (2014, p. 20), "storage allows suppliers ... to counter upstream producer market power". The decrease in $\mathrm{E}q_2$ has a two-fold impact on the marginal value of storage. For one thing, it reduces the present value of each unit of energy stored $\beta(\mathrm{E}q_2 + \tau_2)$. This negative effect is captured by the fourth term. For another, it raises expected date-2 profit net of the benefits of storage (i.e., $\mathrm{E}\pi_{j2} - (\mathrm{E}q_2 + \tau_2)s_j$), as energy becomes cheaper. This is captured by the fifth term on the left-hand side. As one would expect, these strategic effects vanish as foreign energy production becomes perfectly competitive (i.e., as $K \to \infty$ and $q_2 \to \omega c_2$).

The negative coefficient on $\sum_{j'=1}^{J} s_{j'}$ in the first term is larger in absolute value than the coefficient on $\sum_{j'=1}^{J} s_{j'}$ in the fifth term: $J + 1 \ge 2 > 2/[J(K+1)]$. Since, irrespective of whether γ equals 1 or 2, s_j enters the other terms with a negative coefficient, marginal profit is strictly decreasing in s_j. Hence, optimum storage s_j is uniquely determined and positive or zero, depending on whether the intercept is positive or not. As j's marginal profit is decreasing in $s_{j'}$ for $j' \ne j$, the producers' storage activities are *strategic substitutes*, and a joint reduction in s_j by all j raises profit.

We solve for a symmetric equilibrium in which all firms j choose the same amount of storage $s_j = s$ $(j = 1, \dots, J)$, so that (8) can be rewritten as

$$s = \begin{cases} \max\left\{\frac{\lambda - \eta - (1+\delta)(q_1 + \tau_1)}{\mu - \eta}, 0\right\}, & \text{for } \gamma = 1 \\ \max\left\{\frac{\lambda - (q_1 + \tau_1)}{\mu + \delta(q_1 + \tau_1)}, 0\right\}, & \text{for } \gamma = 2 \end{cases}, \tag{9}$$

where

$$\lambda \equiv \beta\left[\frac{K\omega \bar{c}_2 + \bar{\alpha}_2 - (\bar{a}_2 + \tau_2)}{K + 1} + \tau_2\right] + 2\beta\frac{K}{J(J + 1)(K + 1)^2} \times [\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2 + \tau_2)] > 0$$

and

$$\mu \equiv \eta - 2\beta\frac{1}{(I + \theta I')J(K + 1)^2} + \beta\frac{(J + 1)^2}{(I + \theta I')J(K + 1)} > \eta$$

are constants (see Appendix A.7). $\mu > \eta$ follows from $(J+1)^2(K+1) > 2$. An increase in the date-1 import price reduces storage whenever $s > 0$:

$$0 > \frac{ds}{dq_1} = \begin{cases} -\frac{1+\delta}{\mu - \eta}, & \text{for } \gamma = 1 \\ -\frac{\mu + \delta\lambda}{[\mu + \delta(q_1 + \tau_1)]^2} & \text{for } \gamma = 2 \end{cases}. \tag{10}$$

The function, given by (9), that relates s to q_1 has a kink at the value q_1^0 at which s drops to zero. Accordingly, ds/dq_1 jumps upwards at q_1^0, from the negative value given by the right-hand side of (10) (evaluated at q_1^0 for $\gamma = 2$) to zero.

Energy producers choose their date-1 outputs z_{k1} so as to maximize $\psi_{k1} + \beta \mathrm{E} \psi_{k2}$, given the industrial goods sector's reaction functions. Using symmetry, the necessary condition for profit maximization $\partial(\psi_{k1} + \beta \mathrm{E} \psi_{k2})/\partial z_{k1} = 0$ can be written as

$$\begin{aligned} q_1 = \omega c_1 &+ \frac{\frac{1}{K}\left\{\iota[\alpha_1 - (q_1 + a_1 + \tau_1)] + \left(s + \delta\frac{s^\gamma}{\gamma}\right)\right\}}{\iota - \left(1 + \delta s^{\gamma - 1}\right)\frac{ds}{dq_1}} \\ &- \frac{\frac{2\beta}{(K+1)^2}\left[\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2 + \tau_2) - \frac{1}{\iota}s\right]\frac{ds}{dq_1}}{\iota - \left(1 + \delta s^{\gamma - 1}\right)\frac{ds}{dq_1}}, \end{aligned} \tag{11}$$

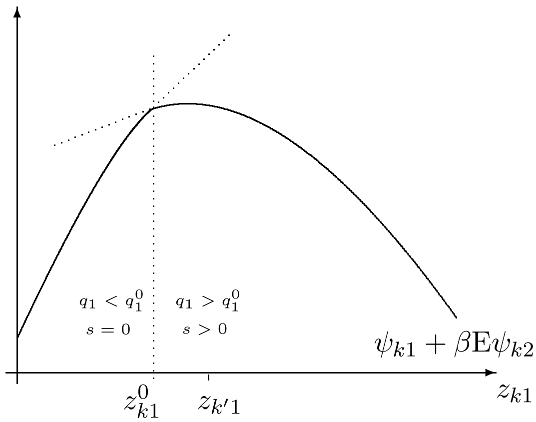

Fig. 2. Concavity of energy producers' profit function.

where $\iota \equiv (I+\theta I')/(J+1)$ (see Appendix A.8). Due to the discontinuity in ds/dq_1, an additional assumption is required in order to make sure that $\psi_{k1} + \beta \mathrm{E}\psi_{k2}$ is a concave function of z_{k1}, so that the necessary optimality condition yields a profit maximum (see Fig. 2). To see this, suppose all energy producers k' choose the same output $z_{k'1}$. The market clearing price q_1 solves

$$K z_{k'1} = J\iota[\alpha_1 - (q_1 + a_1 + \tau_1)] + J\left(s + \delta\frac{s^\gamma}{\gamma}\right).$$

The two terms on the right-hand side are the date-1 energy demands for immediate use and for storage, respectively. Suppose $s > 0$. Let a single firm k reduce its output to the level z_{k1}^0 defined by

$$z_{k1}^0 + (K-1)z_{k'1} = J\iota[\alpha_1 - (q_1^0 + a_1 + \tau_1)].$$

The right-hand side is energy demand at price q_1^0, which yields $s = 0$. So z_{k1}^0 is the firm-k output that leads to $s = 0$, holding competitors' supplies constant. As k's output falls below z_{k1}^0, q_1 rises above q_1^0. As shown above, this leads to an upwards jump in ds/dq_1 (from negative to zero), which also causes a jump in k's marginal profit $\partial(\psi_{k1} + \beta\mathrm{E}\psi_{k2})/\partial z_{k1}$. If the size of this jump is positive and sufficiently large, then k's profit can be higher at an output level below z_{k1}^0 than at $z_{k'1}$. This can be ruled out by assuming that either $z_{k1}^0 \le 0$ or

$$0 < z_{k1}^0 \le 2\beta\frac{J\iota}{(K+1)^2}\left[\bar{\alpha}_2 - (\omega\bar{c}_2 + \bar{a}_2 + \tau_2)\right] \tag{12}$$

(see Appendix A.9). In the former case, marginal profit is continuous for all $z_{k1} \ge 0$. Condition (12) implies that marginal profit jumps upwards as z_{k1} falls below z_{k1}^0 otherwise (i.e., profit is concave at z_{k1}^0).

Equilibrium:

We are now in a position to collect the equations and inequality conditions that determine equilibrium quantities and prices. Substituting for ds/dq_1 from (10) into (11) yields an equation in s and q_1 alone. This equation and (9) jointly determine the equilibrium values of s and q_1. The equilibrium values of the other endogenous quantities and prices can be obtained from (2)–(7) (p_1 from (7), q_2 from (4), etc.). It is easily checked that the markets for loans, goods, and labor clear and trade is balanced at both dates if asset holdings are zero for all i and the home country exports $Jq_1(x_{j1} + s + \delta s^\gamma/\gamma) - I'p_1\theta e_{i1}$ units of the consumption good at date 1 and $Jq_2(x_{j2} - s) - I'p_2\theta e_{i2}$ at date 2 in exchange for its energy imports (see Appendix A.10).

We distinguish between *equilibria with storage* (i.e., with $s > 0$) and *equilibria without storage* (i.e., with $s = 0$). Equilibria without storage are much easier to characterize analytically: as storage is the only important link between the two dates, an equilibrium without storage is simply a sequence of two "static" equilibria (recalling that, as just noted, zero asset holdings are compatible with equilibrium). In order to isolate the effects of storage, we sometimes compare equilibria with and without storage. To do so, we consider two economies which differ only with respect to the input requirements in storage η and/or δ. In one economy, the input requirements are sufficiently low so that an equilibrium with storage obtains, whereas the cost of storage is prohibitive in the other economy (as, e.g., $\eta \to \infty$), so that an equilibrium without storage emerges.

Equilibrium has to satisfy several consistency requirements. First of all, all prices have to be strictly positive. For an equilibrium with storage, we have to check two further consistency requirements. For one thing, storage must not exceed date-2 sales (i.e., s satisfies (5)). For another, energy producers' profit has to be a concave function of their output (i.e., z_{k1}^0 is non-positive or satisfies (12)).

Closed-form solutions:

An equilibrium without storage allows for closed form solutions for the endogenous variables. From (4) and (11) with $s = 0$ and $ds/dq_1 = 0$,

$$q_t = \frac{K\omega c_t + \alpha_t - (a_t + \tau_t)}{K+1} \tag{13}$$

($t = 1, 2$). The other equilibrium prices and quantities are obtained by recursive substitution.

A second special case that allows for closed-form solutions is perfect competition in foreign energy production (which waives the successive oligopolies structure of the model). There is no feedback from storage to the energy prices then: $q_t \to \omega c_t$ for $K \to \infty$ ($t = 1, 2$). With constant marginal cost of storage (i.e., for $\gamma = 1$), an equilibrium with storage does not exist: in the condition for optimum storage (8), the final two terms drop out, and the sum of the first three terms (marginal profit holding prices constant) is independent of s_j (and, hence, generally different from zero). For $\gamma = 2$, one obtains $\lambda \to \beta(\omega\bar{c}_2 + \tau_2)$, $\mu \to \eta$, and, from (9),

$$s = \frac{\beta(\omega\bar{c}_2 + \tau_2) - (\omega c_1 + \tau_1)}{\eta + \delta(\omega c_1 + \tau_1)}. \tag{14}$$

Storage as a negative-NPV activity:

Several industrial organization partial equilibrium analyses investigate the incentives for strategic over-investment in storage. For instance, Pal (1991) shows that firms have an incentive to produce early rather than when unit cost is minimum, in order to deter competitors. In Baranes et al. (2014, p. 22), there can be "strategic storage" in that $s_j > x_{j2}$ (in our notation), which requires that there is another market in which excess the supply can be sold. Our model gives rise to a related notion of over-investment in storage: firms may engage in storage activity even though it is a negative net present value (NPV) activity *holding prices constant.*

To see this, let $\gamma = 2$. Starting from an equilibrium with $s > 0$, let a model parameter change so that storage goes to zero. Recall that the sum of the first two terms in (8) is $\beta\left(\mathrm{E}q_2 + \tau_2\right) - \left(q_1 + \tau_1\right)$. From the fact that the third and fourth effects vanish as $s \to 0$, while the fifth term is positive and bounded away from zero, we obtain:

Proposition 1. *For $\gamma = 2$, $\beta(\mathrm{E}q_2 + \tau_2) - (q_1 + \tau_1) < 0$ at an equilibrium with s positive but sufficiently small.*

Recall that the fifth term in (8) captures one of the two strategic effects of storage: an increase in s_j reduces the expected energy price $\mathrm{E}q_2$, thereby raising expected date-2 profit net of the benefits of storage. This strategic effect makes it profitable for industrial goods producers to store small amounts of energy even if the current energy price exceeds the discounted expected date-2 price.[6] The strategic substitutes property of storage means that industrial goods producers would benefit from cutting their investments in storage in lockstep.

[6] For $\gamma = 1$, the third (marginal cost) term in (8) is negative and independent of s_j. So the NPV of storage for given prices can be positive or negative at $s = 0$.

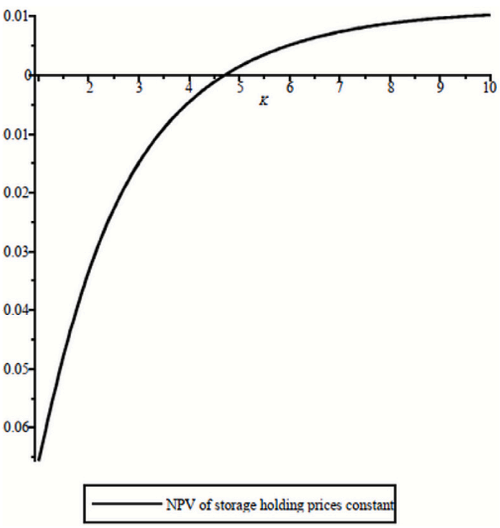

Fig. 3. Net present value (NPV) of storage as a function of the number of foreign oligopolists (K).

Example 1. Consider the following ERMI example, with a domestic monopolist, ten foreign oligopolists, no tariffs, and $\alpha_2-(\omega c_2+a_2)$ binary.

I	I'	ω	J	α_1	$\bar{\alpha}_2$	θ	β	a_1	$\bar{a}_2$	c_1	$\bar{c}_2$	σ^2	η	δ	γ	τ_1	τ_2
5	10	0.5	1	3.5	3.5	1	1	2	2	2	2	0.1	0.05	0	2	0	0

Let $K \in \{1,2,3,4\}$. There exist q_1 (>0), s (>0), and ds/dq_1 (<0) that satisfy (9)–(11). Storage s ranges between 0.7117 (for $K=1$) and 1.0576 (for $K=4$). $\mathrm{E}q_2$ falls from 1.2026 to 1.0718 as K rises from 1 to 4, so $q_2>0$ with certainty if the lower bound of the support of c_2 is sufficiently large. As for the two consistency requirements for an equilibrium with storage, condition (6) is satisfied, as the right-hand side is equal to 1.3783. For $K=1$, condition (12) reads $0<0.9375\le 1.8750$. For $K=2$, $K=3$, and $K=4$, z_{k1}^0 is negative (−0.1088, −0.5677, −0.7762, resp.). The NPV of storage holding prices constant $\beta\mathrm{E}q_2-q_1$ is −0.0657, −0.0334, −0.0149, and −0.0046, respectively (see Fig. 3).

4. Welfare

This section calculates the levels of utility obtained by consumers in equilibrium and decomposes these total utilities into separate parts, viz., labor income, profit income, income from energy arbitrage, tariff revenue, and consumer surplus. We prove gains from trade for consumers in both countries and show that, in spite of the benefits of energy arbitrage, storage potentially reduces domestic consumers' equilibrium utility.

Equilibrium utilities:

The equilibrium values of $\mathrm{E}[(\alpha_2-p_2)^2]$ and $\mathrm{E}q_2$ can be written as

$$\Psi(s)\equiv\left(\frac{J}{J+1}\frac{K}{K+1}\right)^2\left\{\left[\bar{\alpha}_2-(\omega\bar{c}_2+\bar{a}_2+\tau_2)+\frac{J+1}{(I+\theta I')K}s\right]^2+\sigma^2\right\}$$

and

$$\Phi(s)\equiv\frac{K\omega\bar{c}_2+\bar{a}_2-(\bar{a}_2+\tau_2)-\frac{J+1}{I+\theta I'}s}{K+1},$$

respectively (see Appendices A.4 and A.5). Using these definitions, the level of utility achieved by a domestic consumer in equilibrium (also called domestic welfare in what follows) is

$$\begin{aligned}u_{i1}+\beta\mathrm{E}u_{i2}=1+\beta\;&+\left(\frac{I+\theta I'}{IJ}+\frac{1}{2}\right)\left\{\left(\frac{J}{J+1}\right)^2\left[\alpha_1-(q_1+a_1+\tau_1)\right]^2\right.\\&\left.+\;\beta\Psi(s)\right\}\\&+\frac{J}{I}\left\{\left[\beta\Phi(s)-q_1\right]s-(\eta+\delta q_1)\frac{s^\gamma}{\gamma}\right\}\\&+\frac{(I+\theta I')J}{I(J+1)}\left(\tau_1\left[\alpha_1-(q_1+a_1+\tau_1)\right]\right.\\&\left.+\;\beta\tau_2\left\{\bar{\alpha}_2-\left[\Phi(s)+\bar{a}_2+\tau_2\right]\right\}\right),\end{aligned}\qquad(15)$$

where q_1 and s are the equilibrium values determined by (9)–(11) (see Appendix A.11). Due to quasi-linearity of the utility function, total utility can be decomposed as follows.

Labor income: $1+\beta$ is the present value of labor income.

Profit income: $(I+\theta I')/(IJ)$ times the first term in braces on the right-hand side of (15) is the present value of profit income net of the benefits and costs of storage (the two terms in braces correspond to date-1 and date-2 net profits, respectively).

Consumer surplus: $1/2$ times the first term in braces in (15) is the present value of the utility gain resulting from diverting the optimum amount of income to the industrial good (the two terms in braces correspond to date 1 and date 2, respectively).

Income from energy arbitrage: The second term in braces in (15) is the contribution of energy arbitrage to the expected present value of industrial goods producers' profits (i.e., the difference between $\beta(\mathrm{E}q_2-q_1)s$ and storage cost).

Tariff revenue: The final term in (15) is the present value of tariff revenue per capita.

The present value of labor income is fixed unless β changes. The portions of changes in total utility that can be attributed to the latter four effects are called the *profit income, consumer surplus, arbitrage income,* and *tariff revenue effects*, respectively, of a parameter change. The profit income and consumer surplus effects go in the same direction for any parameter change that leaves $(I+\theta I')/(IJ)$ unaffected. Arbitrage income turns out to be negative for many parameterizations of the model (see the examples below). This is because storage does not maximize arbitrage income but is also used strategically to influence the price of energy (see the discussion of optimality condition (8)). This result is related to the stronger result in Proposition 1, which states that the payoff to arbitrage can be negative *excluding cost*.

A foreign consumer's equilibrium utility (also called foreign welfare) is

$$\begin{aligned}u_{i1}+\beta\mathrm{E}u_{i2}=(1+\beta)\omega\;&+\frac{J}{I'}(q_1-\omega c_1)\left\{\frac{I+\theta I'}{J+1}[\alpha_1-(q_1+a_1+\tau_1)]\right.\\&\left.+\left(s+\delta\frac{s^\gamma}{\gamma}\right)\right\}\\&+\beta\frac{(I+\theta I')JK}{I'(J+1)}\left\{\left[\Phi(s)-\omega\bar{c}_2\right]^2+\frac{1}{(K+1)^2}\sigma^2\right\}\\&+\frac{\theta}{2}\left\{\left(\frac{J}{J+1}\right)^2[\alpha_1-(q_1+a_1+\tau_1)]^2+\beta\Psi(s)\right\}\end{aligned}\qquad(16)$$

(see Appendix A.12). The first term is labor income, the sum of the second and third terms is the present value of per capita profits in energy production, and the final term is consumer surplus.

Gains from trade:

Evidently, there are gains from trade for both countries:

Proposition 2. *Let $\tau_t\ge 0$ ($t=1,2$) and $\theta=1$ or K finite. Then $u_{i1}+\beta\mathrm{E}u_{i2}$ is strictly greater than in autarky for all consumers.*

In the absence of international trade, output of the industrial good is zero, as only the home country has the ability to produce it, but lacks the required energy inputs. As a consequence, domestic and foreign consumers' equilibrium utilities are given by labor income alone. Positive consumer surplus implies gains from trade for domestic consumers. In the ERMI model with trade in the industrial good (i.e., for $\theta=1$), foreign consumers likewise get positive consumer surplus and, therefore, positive gains from trade. In the ECG model (where $\theta=0$), their gains from trade are strictly positive if energy production is imperfectly competitive (i.e., K is finite), so that profit income is strictly positive.

The assertion of Proposition 2 is in line with the well known result that, moving from autarky to trade with or without tariffs, there are gains from trade if tariff revenue is positive (see Feenstra, 2016, p. 199).

Closed-form solutions:

The closed-form solutions for equilibrium prices and quantities can be used to calculate closed-form solutions for consumers' equilibrium utilities in the two special cases considered in Section 3, viz., no storage or perfect competition in energy production.

Define $\omega_i = 1$ for domestic consumers i and $\omega_i = \omega$ for foreign consumers i. Further, define

$$Y_i = (1+\beta)\omega_i + \xi_i \left\{ \left[\alpha_1 - (\omega c_1 + a_1 + \tau_1)\right]^2 + \beta\left[\bar{\alpha}_2 - (\omega\bar{c}_2 + \bar{a}_2 + \tau_2)\right]^2 + \beta\sigma^2 \right\}, \tag{17}$$

where

$$\xi_i = \begin{cases} \left(\frac{I+\theta I'}{IJ} + \frac{1}{2}\right)\left(\frac{J}{J+1}\frac{K}{K+1}\right)^2, & \text{for } i \text{ domestic} \\ \left[\frac{(I+\theta I')(J+1)}{I'JK} + \frac{\theta}{2}\right]\left(\frac{J}{J+1}\frac{K}{K+1}\right)^2, & \text{for } i \text{ foreign} \end{cases}, \tag{18}$$

and

$$\Lambda = \frac{(I+\theta I')JK}{I(J+1)(K+1)}\left\{\tau_1\left[\alpha_1 - (\omega c_1 + a_1 + \tau_1)\right] + \beta\tau_2\left[\bar{\alpha}_2 - (\omega\bar{c}_2 + \bar{a}_2 + \tau_2)\right]\right\}. \tag{19}$$

Then, the expressions for utility in an equilibrium without storage (15) and (16) simplify to

$$u_{i1} + \beta \mathrm{E} u_{i2} = \begin{cases} Y_i + \Lambda, & \text{for } i \text{ domestic} \\ Y_i, & \text{for } i \text{ foreign} \end{cases} \tag{20}$$

(see Appendix A.13). Y_i is the sum of labor income, profit income, and consumer surplus, and Λ is tariff revenue.

With perfect competition in energy production (for $K \to \infty$), the utilities in an equilibrium with storage are given by

$$u_{i1} + \beta \mathrm{E} u_{i2} = \begin{cases} Y_i + \Lambda + \frac{J}{2I}\frac{\left[\beta(\omega\bar{c}_2+\tau_2)-(\omega c_1+\tau_1)\right]^2}{\eta+\delta(\omega c_1+\tau_1)}, & \text{for } i \text{ domestic} \\ Y_i, & \text{for } i \text{ foreign} \end{cases}, \tag{21}$$

where ξ_i is the limit of (18) as $K \to \infty$ here and the final term in the first line on the right-hand side is income from energy arbitrage (see Appendix A.14).

Welfare effects of storage:

The main function of storage is to allow smooth consumption without large variations in marginal cost and price. The economic benefits of this energy arbitrage are obvious. Accordingly, access to storage generally raises welfare in competitive environments. It has been recognized, however, that the welfare effects of storage are ambiguous in imperfectly competitive environments (see, e.g., Sioshansi, 2010, 2014; Schill and Kemfert, 2011).

We proceed to show that in our model, independent of market concentration at home, perfect competition *abroad* is sufficient for welfare gains due to storage for domestic consumers, while the welfare effects are ambiguous when energy producers are oligopolists:

Proposition 3. *$u_{i1} + \beta \mathrm{E} u_{i2}$ is higher for domestic consumers i at an equilibrium with storage than at an equilibrium without storage for $K \to \infty$. For K finite, there exist parameters such that $u_{i1}+\beta \mathrm{E} u_{i2}$ is lower for domestic consumers i at an equilibrium with storage than at an equilibrium without storage.*

Consider first the case of perfect competition abroad. As shown above, domestic consumers' utility is given by (20) in an equilibrium without storage and by (21) in an equilibrium with storage. As Y_i and Λ are independent of the parameters that characterize the storage technology, the domestic welfare gain due to storage is equal to arbitrage income (the final term on the right-hand side of (21)). Foreign consumers' equilibrium utility Y_i is unaffected by storage, so that domestic welfare gains do not come at the expense of foreign consumers.

Next, consider the case of imperfect competition among foreign energy producers. An example of a welfare loss for domestic consumers with a straightforward interpretation in terms of the model's mechanics is based on the fact that energy producers' profit function $\psi_{k1} + \beta \mathrm{E}\psi_{k2}$ is kinked at the output level z^0_{k1} above which s turns positive if $z^0_{k1} > 0$ (see Fig. 2). Condition (12) ensures that the profit function is concave, i.e., marginal profit jumps *downwards* at z^0_{k1}. Hence, energy producers' have stronger incentives to raise date-1 output at an equilibrium without storage (and $z_{k1} < z^0_{k1}$) than at an equilibrium with a small positive amount of storage (and $z_{k1} > z^0_{k1}$). This pro-competitive effect potentially makes an equilibrium without storage more attractive to domestic consumers than an equilibrium with a small positive amount of storage. The following example proves that appropriate model parameters exist.

Example 2.

I	I'	ω	J	K	α_1	$\bar{\alpha}_2$	θ	β	a_1	$\bar{a}_2$	c_1	$\bar{c}_2$	σ^2	δ	γ	τ_1	τ_2
50	50	0.5	2	2	2.5	5	1	0.95	1	2	1.5	3	0.1	0	1	0	0

There are q_1 (>0), s (>0), and ds/dq_1 (<0) that satisfy (9)–(11) for η up to 0.9654. Let $a_2 - (\omega c_2 + a_2)$ be binary. Then $q_2 > 0$ with certainty if the lower bound of the support of c_2 is large enough, and consistency condition (6) is satisfied for $\eta > 0.4385$. z^0_{k1} rises from −59.0498 to 15.3278 as η rises from 0.4385 to 0.9654, and the expression on the far right-hand side of (12) is 21.1111, so the condition is also satisfied and an equilibrium with storage exists for η in between 0.4385 and 0.9654.

Fig. 4 illustrates domestic consumers' equilibrium utility and its components for the admissible range of values of η. Domestic utility is more than one-fifth higher with than without storage for η at the lower bound of this interval. Interestingly, as η rises, arbitrage income turns negative at $\eta = 0.5839$ and remains so for η up to the upper bound of the interval of admissible values. This illustrates that the value of energy arbitrage (including cost) can be negative in equilibrium, even though the NPV of storage (*excluding cost*) holding prices constant is positive (as it is for all admissible η in the present example).

As η reaches the level that leads to zero storage (i.e., 0.9654), as explained above, foreign energy producers' profit function flattens out (see Fig. 2), so domestic profit income and consumer surplus jump upwards. Since arbitrage income is a continuous function of η, it follows that there is an open interval of non-zero length of η values (here: $(0.9271, 0.9654)$) that lead to lower equilibrium utility with than without storage.

5. Tariffs

Following the seminal contribution of Spencer and Jones (1991), a branch of the literature on trade policy in imperfectly competitive markets investigates the case of vertically related markets. This section adds a novel case to this branch of the literature by analyzing optimum import tariffs in our successive oligopolies model.[7] We show that in an equilibrium without storage, the home country's optimum tariff is positive if market concentration is higher abroad than at home. Numerical analysis confirms that the optimum tariff is also usually positive in an equilibrium with storage.[8]

[7] An interesting question addressed by Spencer and Jones (1991) and subsequent authors is whether foreign intermediate goods producers (e.g., energy producers) have incentives to price domestic final goods producers out of the market. Given that the foreign country is unable to produce the industrial good, such vertical foreclosure cannot happen in our model.

[8] Alternatively, following Brander and Spencer (1985) and part of the literature on vertically related markets, one could analyze export subsidies as

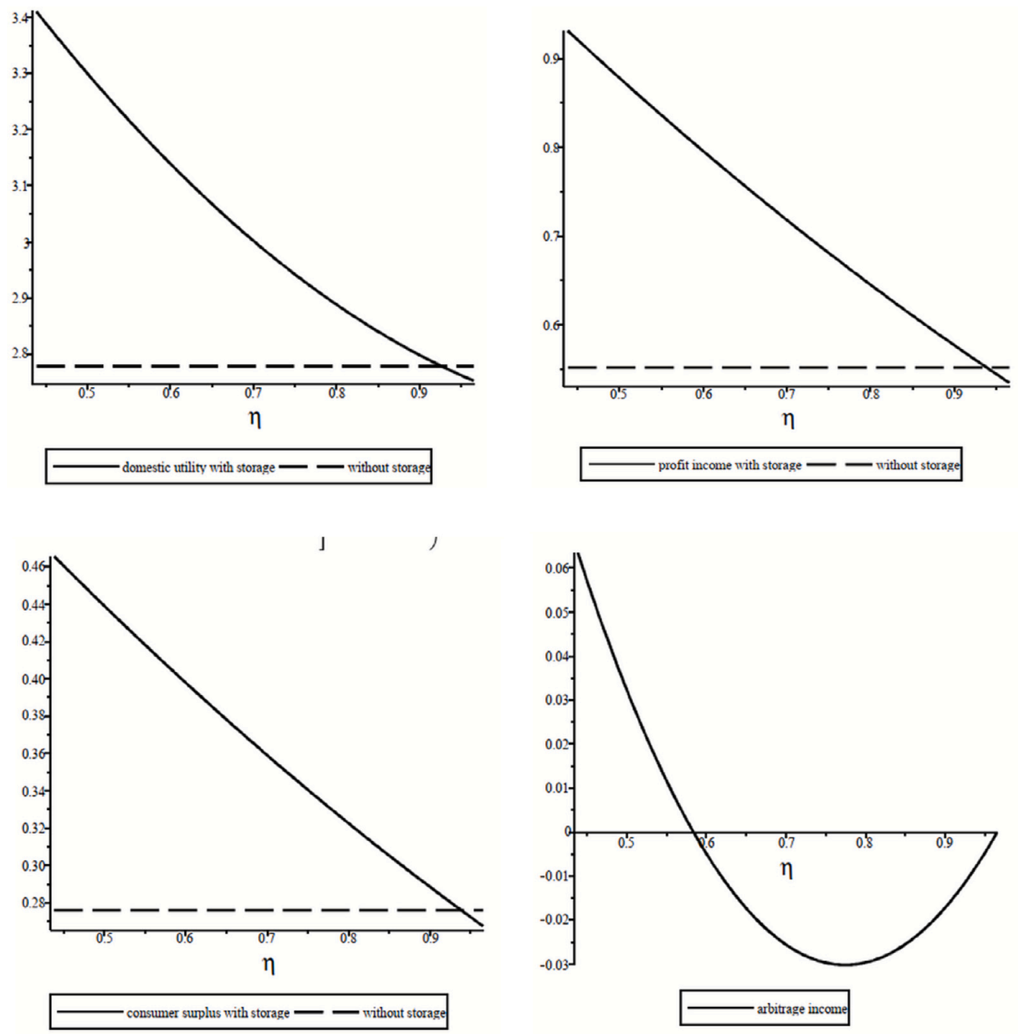

Fig. 4. Domestic utility and its components with and without storage as a function of the labor requirements for storage (η).

Equilibrium without storage:

Consider first equilibria without storage. From (20), a domestic consumer's utility is $Y_i + \Lambda$, where Y_i the sum of labor income, profit income, and consumer surplus, and Λ is tariff revenue per capita. It is a strictly concave function of τ_1 and τ_2 (see Appendix A.15). So the optimum tariff τ_t is positive exactly if the partial derivative of $Y_i + \Lambda$ with respect to τ_t is positive at $\tau_t = 0$.

From (13), $\partial q_t/\partial \tau_t = -1/(K+1) < 0$. That is, as a large country, the home country can improve its terms of trade by raising import tariffs (cf. Feenstra, 2016, pp. 221 f.). The improvement in its terms of trade notwithstanding, an increase in τ_t reduces the sum of profit income and consumer surplus: from (1) and (17), $\partial Y_i/\partial \tau_t < 0$ ($t = 1, 2$). On the other hand, the tariff revenue effect is positive (i.e., $\partial \Lambda/\partial \tau_t > 0$) for τ_t positive but small enough. The following result states that the tariff revenue effects dominates the profit income and consumer surplus effects for small tariff rates, so that the optimum tariff is positive, if domestic market concentration is not too low:

Proposition 4. *At an equilibrium without storage, for domestic consumers i, $\partial(u_{i1} + \beta \mathrm{E} u_{i2})/\partial \tau_t > 0$ at $\tau_t = 0$ for $t = 1, 2$ exactly if*

$$J + 1 > \left(1 - \frac{\theta I'}{I + \theta I'} J\right) K.$$

For foreign consumers i, $\partial(u_{i1} + \beta \mathrm{E} u_{i2})/\partial \tau_t < 0$ for $t = 1, 2$.

The proof is in Appendix A.15. The second part says that foreign consumers suffer from the tariff imposed on their exports.[9]

Let $\theta = 1$. The condition of the proposition is satisfied if the number of domestic firms satisfies $J > 1 + I/I'$ (which implies that the right-hand side is negative). This is in line with standard trade theory: the optimum import tariff is positive for a large country under perfect competition (see Feenstra, 2016, pp. 222) and, hence, for sufficiently intensive competition (i.e., J sufficiently large). A second sufficient condition is $J + 1 > K$, i.e., market concentration is higher abroad than at home. Boots et al. (2004) argue that this is typical of energy markets,

the instrument of trade policy. Tariffs are the more common trade policy instrument because of the obstacles to implementing welfare-improving subsidies in practice (see Feenstra, 2016, pp. 292 f., 296 f.).

[9] We also checked the outcome of strategic trade policy (i.e., non-cooperative import tariffs in both countries) at an equilibrium without storage. With perfect competition, the foreign country chooses a zero import tariff on the industrial good and the domestic tariff is determined as in Proposition 4 in a Nash equilibrium of the tariff setting game. With imperfect competition, the domestic tariff is positive and most likely (for instance, with successive duopolies) even greater, while the foreign tariff tends to be negative.

where many countries' energy imports stem from a small number of state-controlled foreign firms. The condition $J+1>K$ is satisfied whenever $K=1$. This is in line with the well known result that with linear demand and cost functions, the optimal specific tariff on the sales of a foreign monopolist selling into the domestic market is positive (see Brander and Spencer, 1984; Feenstra, 2016, pp. 224 ff.). The condition in Proposition 4 is violated, and the optimum import tariff is negative, if the number of domestic firms J is sufficiently small. The reason why can be seen from Eqs. (17)–(19). As J becomes small, firm profits and, hence, the negative profit income effect grow large in absolute value (ξ_i and $|\partial Y_i/\partial\tau_1|$ grow large). At the same time the positive tariff revenue effect ($\partial\Lambda/\partial\tau_t$) becomes small. So the revenue generated by a small positive tariff does not compensate for the losses in profit income and consumer surplus.

Equilibrium with storage:

By continuity, if the condition in Proposition 4 is satisfied, the optimum import tariff is positive at an equilibrium with a positive but small amount of storage. Numerical analysis shows that the sign of the optimum import tariff remains positive for a wide range of parameters. As the following example illustrates, it is not possible, however, to rule out a switch in the optimum import tariff from positive to negative theoretically.

Example 3.

I	I'	ω	J	K	α_1	$\bar{\alpha}_2$	θ	β	a_1	$\bar{a}_2$	c_1	$\bar{c}_2$	σ^2	η	δ	γ	τ_2
50	100	0.5	3	3	3	18	1	0.95	1	2	1.5	3	0.1	0.01	0	1	0

In an equilibrium without storage (i.e., for η prohibitively high), the derivative of domestic utility with respect to the date-1 tariff is $\partial(u_{i1}+\beta \mathrm{E}u_{i2})/\partial\tau_1 = 0.9229$ at $\tau_1=0$, so the optimum import tariff τ_1 is positive (the jointly sufficient conditions $\theta=1$ and $J>1+I/I'$ are satisfied). It is equal to $\tau_1=0.3804$ or 39.3 percent of the import price q_1. High demand at date 2 ($\bar{\alpha}_2=6\alpha_1$) implies grossly different prices without storage (e.g., $q_1=1.0625$ and $\mathrm{E}q_2=5.1250$ for $\tau_1=0$).

The combination of a steep price increase over time and cheap storage ($\eta=0.01$) gives rise to intensive energy arbitrage (storage equals 167.5878 times energy used in production at date 1 for $\tau_1=0$ at an equilibrium with storage). This brings the energy prices closer together ($q_1=1.9348$ and $\mathrm{E}q_2=2.3913$ for $\tau_1=0$). The derivative of domestic utility with respect to the date-1 tariff $\partial(u_{i1}+\beta\mathrm{E}u_{i2})/\partial\tau_1$ at $\tau_1=0$ changes to -0.1683, the optimum tariff τ_1 becomes negative, viz., -0.0131 or -0.6 percent of q_1.

6. Competition

This section addresses the much discussed question of how the intensities of competition in energy production, energy distribution, and energy-intensive manufacturing affect consumer welfare (see, e.g., Boots et al., 2004; Holz et al., 2008). The ECG model confirms the conventional wisdom that a decrease in the number of domestic oligopolists reduces domestic welfare due to stronger double marginalization. In contrast to existing studies, higher market concentration is not generally more harmful if it occurs in the market with higher concentration initially. In the ERMI model, a country's welfare is a hump-shaped (rather than a monotonically increasing) function of the number of resident firms, so from the viewpoint of each country, there is a finite optimum number of resident firms.

Market concentration and welfare:

As before, we derive analytical results for equilibria without storage and check numerically whether they carry over to equilibria with storage. For the sake of simplicity, here and in what follows, ignore tariffs: $\tau_t=0$ ($t=1,2$). This implies $\Lambda=0$, so that, from (20), $u_{i1}+\beta\mathrm{E}u_{i2}=Y_i$ for all i at an equilibrium without storage. From (17), changes in the numbers of oligopolists J and K affect Y_i only via ξ_i. For domestic consumers, from (18), as one would expect, an increase in J decreases profit income (since $d[J/(J+1)^2]/dJ = -(J-1)/(J+1)^3 < 0$ for $J>1$) but increases consumer surplus (since $d\{[J/(J+1)]^2\}/dJ>0$). For foreign consumers, it raises both profit income and, if $\theta=1$, consumer surplus. Conversely, an increase in K reduces foreign consumers' profit income and raises consumer surplus in both countries. Thus, a country benefits from lower market concentration among resident firms if the positive consumer surplus effect is stronger than the negative profit income effect. The following proposition provides necessary and sufficient conditions:

Proposition 5. *At an equilibrium without storage, $u_{i1}+\beta\mathrm{E}u_{i2}$ increases as J rises for domestic consumers i exactly if*[10]

$$1-\frac{\theta I'}{I+\theta I'}J>0. \tag{22}$$

$u_{i1}+\beta\mathrm{E}u_{i2}$ increases as K rises for foreign consumers i exactly if

$$1-\left(1-\frac{\theta I'}{I+\theta I'}\frac{J}{J+1}\right)K>0. \tag{23}$$

The proof is in Appendix A.16. The remainder of this section provides an in detail interpretation and discussion of the conditions of the proposition for the ECG model and for the ERMI model.

Energy as a consumption good:

A decrease in domestic market concentration is detrimental to firm profits made in the domestic market as well as abroad. In the ECG model, domestic energy wholesalers have no foreign sales, so profits made abroad drop out. As a result, the negative impact of more intense competition on profit income is dominated by the positive impact on consumer surplus, and domestic utility goes up (formally, condition (22) is satisfied for $\theta=0$). Our model thus lends support to the conventional view that "[E]nforcing competition in the … downstream market would lead to lower prices and higher quantities by avoiding the welfare-reducing effects of double marginalization" (Holz et al., 2008, p. 766; see also Greenhut and Ohta, 1979; Salinger, 1988). This contrasts with the more skeptical view held by Talus (2014, p. 33), that due to market power in the upstream market, "the potential for a competitive downstream market must be questioned". The interests of foreign consumers are in line with those of domestic consumers, as their consumer surplus goes up.

Differentiating (18) totally for i domestic and setting $\theta=0$ gives

$$\begin{aligned} d\xi_i = {} & \frac{J}{(J+1)^2}\left(\frac{K}{K+1}\right)^2\left[-\frac{J-1}{J(J+1)}dJ+\frac{2}{K(K+1)}dK\right] \\ & +\left(\frac{J}{J+1}\frac{K}{K+1}\right)^2\left[\frac{1}{J(J+1)}dJ+\frac{1}{K(K+1)}dK\right]. \end{aligned} \tag{24}$$

This expression can be used to compare the welfare effects of changes in market concentration at home versus abroad. The first term on the right-hand side is the profit income effect of changes in the numbers of oligopolists, the second term is the consumer surplus effect. Evidently, the consumer surplus effect is larger for $dJ=dJ'$ and $dK=0$ than for $dJ=0$ and $dK=dJ'$ exactly if $J<K$. This is reminiscent of Boots et al.'s (2004, p. 73) finding that a decrease in the number of firms in the market with fewer competitors causes stronger additional distortions than the corresponding decrease in the more competitive market. Taking into account the profit income effect potentially changes the picture, however: while a decrease in K reduces domestic profit, the profit income effect of a decrease in J (the former term in the first term in square brackets) is positive. As a result, domestic consumers may suffer less from increasing market concentration at home, even though the number of oligopolists is already lower than abroad. To see this, set $J=K-1$ in (24) to obtain

$$d\xi_i=\frac{J}{(J+1)^2}\frac{K}{(K+1)^2}\left(\frac{1}{K-1}dJ+dK\right).$$

Setting first $dK=0$ and then $dJ=0$, we get:

[10] More precisely, consumers are better-off with J_2 than with J_1 ($<J_2$) firms if this inequality holds for all $J\in[J_1,J_2]$.

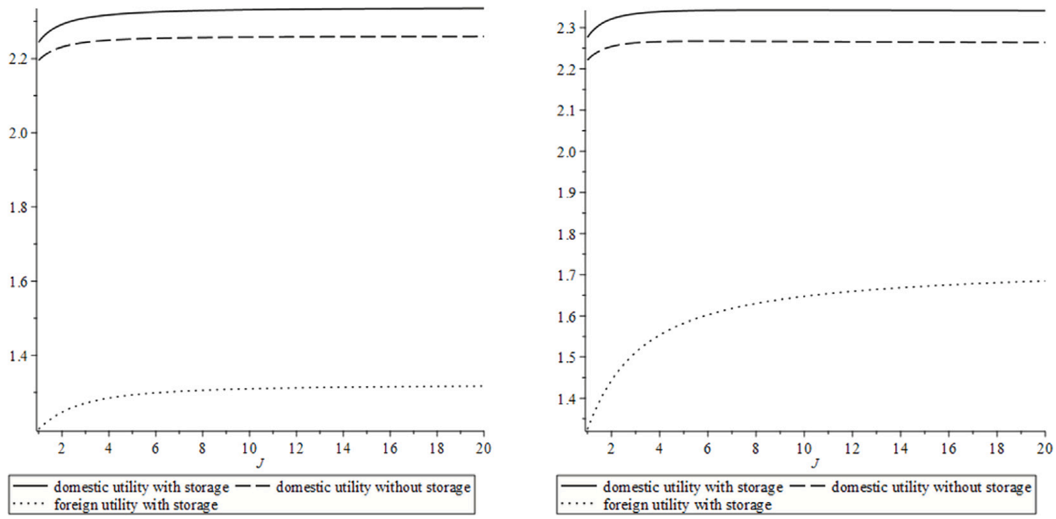

Fig. 5. Utility as a function of the number of domestic oligopolists in the model variants with energy as a consumption good (ECG, left panel) and energy as a raw material for industries (ERMI, right panel).

Proposition 6. *Let $\theta = 0$. If $J = K - 1 > 1$, then*

$$\frac{\partial \xi_i}{\partial J} < \frac{\partial \xi_i}{\partial K}$$

for i domestic at an equilibrium without storage.

Proposition 6 says that whenever the number of domestic wholesalers falls short of the number of foreign energy producers by one, the exit of a wholesaler has a less detrimental impact on domestic welfare than the exit of an energy producer. For instance, domestic consumers are better-off with a domestic monopolist and three foreign energy producers than with successive duopolies.

Condition (23) of Proposition 5 is violated in the ECG model. That is, foreign consumers benefit from more market power for energy producers. This is because profit income rises, while consumer surplus in unaffected, as foreign consumers do not consume energy.

Numerical analysis of the ECG model shows that the result that an increase in the number of domestic oligopolists raises domestic welfare carries over to equilibria with storage. We focus on the case $\gamma = 1$ in the numerical analysis, since convexity of the input requirements for storage (i.e., $\gamma = 2$) would mean that a larger number of firms can store a given quantity of energy (S, say) using less inputs (viz., $J\eta(S/J)^2/2 = \eta S^2/(2J)$).

Example 4.

I	I'	ω	K	α_1	$\bar{\alpha}_2$	θ	β	a_1	$\bar{a}_2$	c_1	$\bar{c}_2$	σ^2	η	δ	γ
250	50	0.5	4	2.5	4	0	1	1	2	1.5	3	0	0.75	0	1

For $J \geq 2$, storage relative to the date-1 energy input in production is between 26 percent and 30 percent. The left panel of Fig. 5 illustrates that, as in the case without storage, both domestic and foreign consumers' equilibrium utilities are increasing functions of the number of domestic oligopolists.

To illustrate Proposition 6, let $K = 5$ instead. Domestic utility for $J = 4$ is 2.3381. As K decreases by one, we are back in the example above, and domestic utility drops to 2.3178. This falls short of domestic utility with $K = 5$ and $J = 3$ (viz., 2.3293). That is, the increase in market concentration in the already more concentrated domestic market is less harmful to domestic consumers than the increase in foreign market concentration.

Energy as a raw material for industries:

Next, consider the ERMI model. Let $\theta = 1$, so that foreign consumers buy domestically produced industrial goods, adding to industrial goods producers' profits. Compared to the ECG model, this aggravates the negative impact of an increase the intensity of competition on profit income. From Proposition 5, the negative profit income effect dominates the positive consumer surplus effect, and more competition among domestic firms reduces domestic welfare (condition (22) is violated) if $J > 1 + I/I'$ in this case. That is, domestic welfare is a hump-shaped function of the number of domestic oligopolists, with its peak at $J = 1 + I/I'$.[11] If there are at least as many foreign as domestic consumers (i.e., $I/I' \leq 1$), then, starting from a duopoly, each additional domestic competitor reduces domestic welfare.[12] Applied to the ERMI model with international trade in the industrial good, Proposition 5 thus implies that a positive amount of market power for its internationally active firms contributes to achieving maximum welfare for domestic consumers.

From condition (23) in Proposition 5, it follows that the effects are similar for foreign consumers: equilibrium utility is a hump-shaped function of the number of energy producers K.

Numerical analysis confirms that welfare is also a hump-shaped function of the number of resident firms in an equilibrium of the ERMI model with storage.

Example 4 (*ctd*). Replace $\theta = 0$ with $\theta = 1$ in Example 4. There is an equilibrium with storage (equal to about 30 percent of date-1 energy input) for any J. As illustrated in the right panel of Fig. 5, domestic utility as a function of the number of domestic oligopolists attains its maximum at $J = 8.7491$. The optimum (integer) number of domestic oligopolists is 9.

7. Subsidizing storage

The drying up of energy imports from Russia after the invasion of Ukraine has directed attention to storage capacities as a counter measure. In Germany, for instance, former Gazprom Export LLC, now SEFE (Securing Energy for Europe), a large storage operator, was nationalized and re-capitalized in 2022.[13] The present section uses our

[11] Incidentally, this is the critical value for J above which the optimum import tariff cannot be negative (cf. Section 5).

[12] The *integer* value of J that maximizes domestic welfare is one or two then. Monopoly is preferred to duopoly exactly if $I/I' < 2/5$. The function that maps the (integer) number of domestic oligopolists to domestic welfare is monotonically decreasing then.

[13] See https://ec.europa.eu/commission/presscorner/detail/6%20en/ip_22_6823 (accessed 22 December 2023).

model to shed some light on the private versus social benefits of energy storage. We show that firms' and the public's interest are aligned and the optimum subsidy is zero if foreign energy production is perfectly competitive. A positive subsidy tends to raise welfare with oligopolistic energy production.

Equilibrium with subsidies to storage:

It is convenient to adapt the notation as follows. Let storing s_j (≥ 0) units of energy cost $\eta' s_j^\gamma/\gamma$ units of labor and $\delta' s_j^\gamma/\gamma$ units of energy, where, similarly as before, $\eta' \geq 0$ and $\delta' \geq 0$, with one inequality strict, and $\gamma \in \{1, 2\}$. Let the domestic government subsidize the labor and energy costs of storage at rate ϕ (<1), so that domestic firms face storage costs $(\eta + \delta q_1)s^\gamma/\gamma$, where $(\eta, \delta) = (1-\phi)(\eta', \delta')$. Budget balance is achieved with a lump-sum tax on domestic consumers equal to

$$\Omega = \frac{J}{I}\phi(\eta' + \delta' q_1)\frac{s^\gamma}{\gamma}. \tag{25}$$

The virtue of the redefinitions of the input coefficients in storage is that equilibrium prices and all equilibrium quantities except domestic consumers' date-1 consumption and exports are determined following the same steps as in Section 3. Domestic date-1 consumption is y_{i1} is reduced by the lump-sum tax Ω, and the home country's date-1 exports of the consumption good are $Jq_1(x_{j1} + s_j + \delta' s_j^\gamma/\gamma) - I' p_1 \theta e_{i1}$. As a consequence, a domestic consumer's total expected utility $u_{i1} + \beta \mathrm{E} u_{i2}$ is obtained by subtracting Ω from the right-hand side of (15). It is the sum of labor income, profit income, arbitrage income, and consumer surplus minus the lump-sum tax. A foreign consumer's total utility is given by (16).

Perfect competition in energy production:

Consider the special case with perfect competition abroad (i.e., $K \to \infty$ and $\gamma = 2$) to begin with. Consumers' utilities are given by (21) with Ω subtracted on the right-hand side and $\Lambda = 0$ for i domestic. Using $q_1 = \omega c_1$, (14), $(\eta, \delta) = (1-\phi)(\eta', \delta')$, and (25), domestic consumer i's utility can be expressed as

$$u_{i1} + \beta \mathrm{E} u_{i2} = Y_i + \frac{J}{2I}\frac{\omega^2(\beta \bar{c}_2 - c_1)^2}{\eta' + \delta' \omega c_1}\left[\frac{1}{1-\phi} - \frac{\phi}{(1-\phi)^2}\right],$$

with ξ_i given by the limit of (18) as $K \to \infty$. From the definition in (17), Y_i is independent of η, of δ, and, hence, of ϕ. As $\phi = 0$ maximizes the term in brackets (the derivative is $-2\phi/(1-\phi)^3$), we have:

Proposition 7. *Let $K \to \infty$ and $\gamma = 2$. Then $\phi = 0$ maximizes domestic consumers' equilibrium utility $u_{i1} + \beta \mathrm{E} u_{i2}$.*

Recall that Y_i is the sum of labor income, profit income, and consumer surplus. As the subsidy does not affect energy prices under perfect competition, this sum is unaffected by the subsidy. As a consequence, the optimum subsidy weighs up additional arbitrage income against the financing cost. That the optimum subsidy is zero is due to the fact that firms' goal to maximize their expected profits is in line with consumers' interest in maximum expected income.

Market power in energy production:

When market power by foreign energy producers is re-introduced, the sum of the profit income and consumer surplus effects no longer vanishes. Numerical analysis shows that the optimum subsidy tends to be positive. The following example shows that this is the case even if welfare is higher without than with storage in the absence of subsidies (i.e., if the conditions of Proposition 3 are satisfied).

Example 2 (*ctd*)**.** Consider Example 2 introduced in Section 4. Set $\eta = 0.9400$ close to the value (viz., 0.9654) at which storage is zero in the absence of subsidies. An equilibrium with storage exists for $\phi > -0.0270$. Without subsidization, domestic welfare is lower than in an equilibrium without storage (see the left panel of Fig. 6). Yet, subsidizing storage raises welfare. For ϕ between 1.7 percent and 34.1 percent, domestic welfare is higher than without storage and subsidies (the optimum subsidy is 17.9 percent). This is because of strong positive profit income and consumer surplus effects, which more than outweigh the cost of financing the subsidy and negative arbitrage income (see the right panel of Fig. 6).

The fact that the optimum subsidy on storage tends to be positive means that public support for storage operators in times of energy shortages does not necessarily distort private storage decisions in the wrong direction.

It is not possible, however, to rule out that the optimum subsidy to storage is negative, as the following example illustrates.

Example 5.

I	I'	ω	J	K	α_1	$\bar{\alpha}_2$	θ	β	a_1	$\bar{a}_2$	c_1	$\bar{c}_2$	σ^2	η'	δ'	γ
10	50	0.5	2	2	2.5	4	1	1	1	2	1.5	3	0	0.5	0	2

The optimum subsidy is −3.9 percent in this example. For $K = 1$, it drops to −8.5 percent.

8. Long term contracts

The choice between long term contracts and spot trade is a much debated theme in energy economics. Traditionally, the focus is on the impact of contracts on the riskiness of investments in production facilities (see, e.g., Abada et al., 2019). Recently, the EU Commission has begun to take measures aimed at curbing the use of long-term contracts, in order to avoid possible interference of pre-specified gas deliveries with greenhouse gas emissions targets.[14] While our model is silent on the impact of long term contracts both on the riskiness of large scale investments in production facilities and on the pursuit of environmental objectives, it sheds light on the role of long term contracts for competition in energy markets: in the presence of storage, long term contracts help importers of energy to reduce import prices and yield higher domestic welfare. This is consistent with a skeptical view of energy exporters on the switch to spot trade.[15]

Long term contracts:

A long term contract specifies the quantity and the price of energy to be delivered at date 2 one date ahead. Accordingly, let q_1 now denote the date-1 spot price of energy and q_2 the price for deliveries at date 2 determined at date 1. As before, energy producers move first: the prices q_1 and q_2 resulting from their output choices are taken as given by the domestic producers. For the sake of simplicity, let α_2, a_2, and c_2 be non-random (so that $\sigma^2 = 0$), and set $\beta = 1$, $\delta = 0$, and $\gamma = 2$.

Consumers maximize u_{i2} at date 2 and $u_{i1} + u_{i2}$ at date 1. This yields the same inverse market demand functions as in the model with spot markets (viz., $p_t = \alpha_t - E_t/(I + \theta I')$, $t = 1, 2$) and $1/(1+r) = 1$.

Industrial goods producer j chooses x_{j1}, x_{j2}, and s_j so as to maximize the present value of her profits $\pi_{j1} + \pi_{j2}$, given the energy prices q_1 and q_2 and the date-1 and date-2 demand functions for industrial goods. This yields

$$p_t = \frac{J(q_t + a_t) + \alpha_t}{J+1} \tag{26}$$

($t = 1, 2$) and

$$s_j = \frac{q_2 - q_1}{\eta} \tag{27}$$

(see Appendix A.17). Storage depends only on the energy price differential and the input requirement for storage. Contrary to the case of spot markets, storage cannot be used to strategically affect the date-2 energy price q_2. The condition $s_j \leq x_{j2}$ reads

$$s_j \leq \iota[\alpha_2 - (q_2 + a_2)].$$

[14] See https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021SC0455 (accessed 22 December 2023).

[15] See https://www.ft.com/content/7f84c0ef-d81b-4d32-a5dc-75cca8e54532 (accessed 22 December 2023).

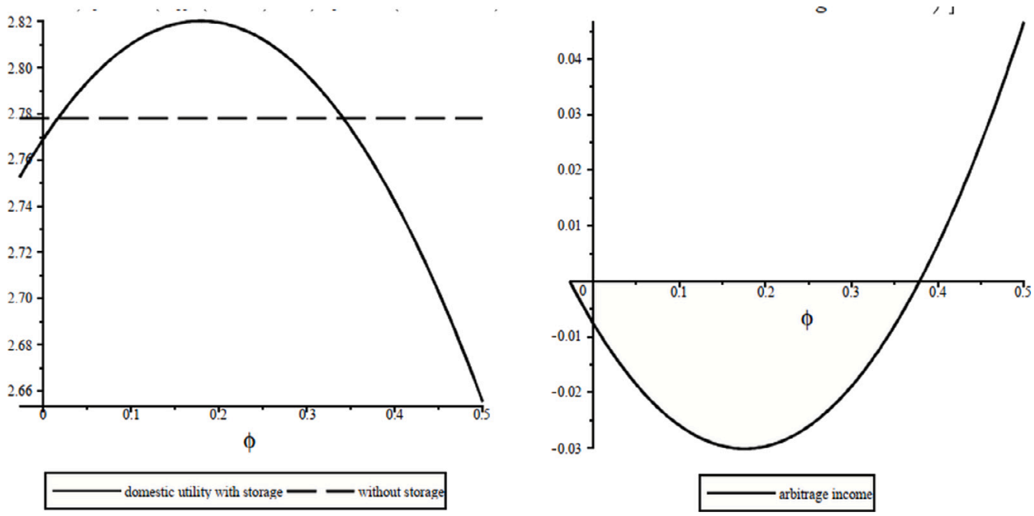

Fig. 6. Domestic utility and income from energy arbitrage as a function of the subsidizing to storage (ϕ).

Energy producer k chooses z_{k1} and z_{k2} so as to maximize $\psi_{k1}+\psi_{k2} = (q_1 - \omega c_1)z_{k1} + (q_2 - \omega c_2)z_{k2}$, taking into account the impact of z_{k1} and z_{k2} on q_1 and q_2 and, hence, s. The resulting energy prices are

$$q_1 = \frac{(\iota\eta + 2)K\omega c_1 + (\iota\eta + 1)(\alpha_1 - a_1) + (\alpha_2 - a_2)}{(\iota\eta + 2)(K + 1)} \tag{28}$$

and

$$q_2 = \frac{(\iota\eta + 2)K\omega c_2 + (\alpha_1 - a_1) + (\iota\eta + 1)(\alpha_2 - a_2)}{(\iota\eta + 2)(K + 1)} \tag{29}$$

(see Appendix A.18).

Equilibrium without storage:

Energy prices in an equilibrium without storage are given by the limits of (28) and (29) as $\eta \to \infty$. These prices coincide with the prices in a spot market equilibrium without storage, reported in (13). Comparing (26) to (3) and (7) shows that p_1 and p_2 also take on the same values in an equilibrium without storage, irrespective of whether long term contracts are traded or there is spot trade. As consumers' demand functions are identical, consumption is also the same with or without long term contracts.

Proposition 8. *Prices q_t and p_t ($t = 1, 2$), consumption, and welfare are the same in an equilibrium without storage with long term contracts as in an equilibrium without storage with spot markets.*

The reason why the type of contract used is immaterial is that, as noted in Section 3, an equilibrium without storage is simply a sequence of two "static" equilibria. Irrespective of whether energy is sold using long term contacts or spot trade, industrial goods producers take the energy prices q_t ($t = 1, 2$) as given at each date. So the sequence of events and, hence, market participants' actions and market outcomes are identical.

Equilibrium with storage:

The use of long term contracts versus spot trade does make a difference for equilibria with storage. With spot trade, storage allows domestic producers to affect the date-2 energy price via their date-1 energy demand and thus "to counter upstream producer market power" (see Baranes et al., 2014, p. 20, and Section 3). Long term contracts shut down this channel and thus lead to higher energy prices q_1 and q_2. This is easy to see in the special case with $\alpha_1 - a_1 = \alpha_2 - a_2$. The energy prices q_1 and q_2 in an equilibrium with long term contracts given by (28) and (29) coincide with the values reported in (13) for all η in this case. From (4) the date-2 spot market price q_2 falls short of this value when $s > 0$. Numerical analysis shows that the date-1 spot market price is also quite generally (though not universally) lower than the equilibrium price with long term contracts:

Example 6.

I	I'	ω	J	K	α_1	$\bar{\alpha}_2$	θ	β	a_1	$\bar{a}_2$	c_1	$\bar{c}_2$	σ^2	δ	γ
50	50	0.5	2	2	2.5	4	1	1	1	2	1.5	3	0	0	2

An equilibrium with long term contracts and storage exists, and date-2 energy input does not fall short of storage for $\eta > 0.0450$. As can be seen from the left panel of Fig. 7, energy prices are higher with long term contracts than with spot trade.

Welfare:

As one would expect, higher energy prices with long term contracts and storage lead to lower domestic welfare than with spot trade.

The equilibrium utilities are calculated analogously as in the case of spot markets. Domestic consumers i get utility

$$\begin{aligned} u_{i1} + u_{i2} = 2 &+ \left(\frac{I + \theta I'}{IJ} + \frac{1}{2}\right)\left(\frac{J}{J+1}\right)^2 \left\{[\alpha_1 - (q_1 + a_1)]^2 \right. \\ &+ \left. [\alpha_2 - (q_2 + a_2)]^2\right\} \\ &+ \frac{J}{I}\left[(q_2 - q_1)s - \eta\frac{s^2}{2}\right], \end{aligned} \tag{30}$$

and foreign consumers achieve utility

$$\begin{aligned} u_{i1} + u_{i2} = &\ 2\omega + \frac{J}{\eta I'}\left\{(q_1 - \omega c_1)[\iota\eta(\alpha_1 - a_1) - (\iota\eta + 1)q_1 + q_2] \right. \\ &+ \left. (q_2 - \omega c_2)[\iota\eta(\alpha_2 - a_2) + q_1 - (\iota\eta + 1)q_2]\right\} \\ &+ \frac{\theta_i}{2}\left(\frac{J}{J+1}\right)^2 \left\{[\bar{\alpha}_1 - (q_1 + a_1)]^2 + [\alpha_2 - (q_2 + a_2)]^2\right\}, \end{aligned} \tag{31}$$

where s, q_1, q_2 are determined by (27)–(29) (see Appendix A.19).

For $\eta \to \infty$ and $s = 0$, the utilities boil down to Y_i, defined in (17). This proves that long term contracts and spot trade lead to the same levels of welfare in equilibria without storage (cf. Proposition 8). Numerical analysis of equilibria with storage shows that, due to higher energy prices, utility is usually lower with long term contracts than with spot trade:

Example 6 (*ctd*). In Example 6, domestic utility is between 0.1 and 1.0 percent lower with long term contracts than with spot markets (see the right panel of Fig. 7).

The fact that domestic utility is lower with long term contracts means that the move away from this type of contracts does not impose costs due to a worsening of domestic firms' strategic position in international competition on domestic consumers.

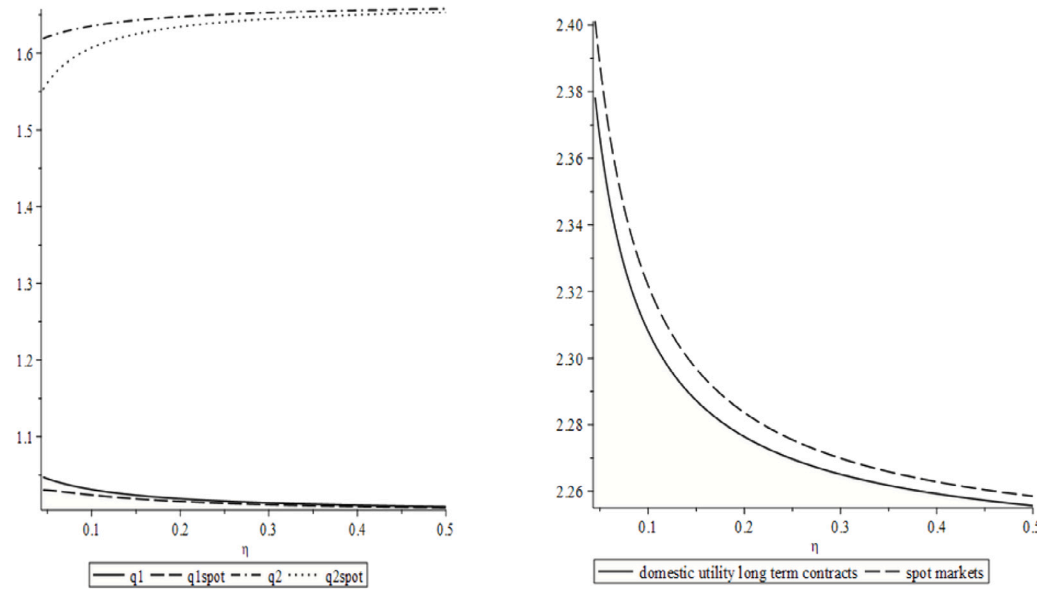

Fig. 7. Energy prices (left panel) and domestic utility (right panel) with long term contracts and spot trade as functions of the labor requirements for storage (η).

9. Conclusions

Energy imports allow resource poor countries to raise their material wealth by specializing in and exporting energy-intensive manufacturing goods. Numerous, in particular European and Eastern Asian, countries adopt this "business model", "Germany's business model" (Fuest, 2022) being a prime example. This paper develops an analytically tractable two-date two-country general equilibrium model that allows it to analyze trade and competition policies, and probably several other issues as well, for such countries.

The model shows that there is potentially strategic over-investment in storage, viz., positive storage despite negative NPV, negative arbitrage income, or lower domestic welfare with than without storage. One avenue for future research is to introduce a longer time horizon and grant a bigger role to risk (as, e.g., in Chaton et al., 2008; Cretì and Villeneuve, 2009). This would allow an integrated analysis of long term versus seasonal fluctuations and a more encompassing analysis of the private versus social costs and benefits of storage. Including strategic storage by energy producers (as in Sioshansi, 2014) might shed further light on the welfare effects of competition in sequential markets.

Long term contracts tend to raise energy prices and reduce the industrial country's welfare in a simple version of the model without risk. A framework with a longer time horizon, a bigger role for risk, and investment in energy production capacities might also be useful in analyzing the trade-offs and synergies between the different effects of long term contracts versus spot trade.

The model shows that the energy dependent country does not have incentives to support domestic export firms with a unilateral negative import tariff. The static version of the model without storage is flexible enough to allow an investigation of strategic trade policy, i.e., tariff games between energy importers and exporters. Including a tariff on industrial imports in the resource rich country tends to raise the optimum domestic import tariff on energy. Further research is required in order to check whether trade wars between importers and exporters of energy can potentially have winners.

The welfare analysis of the model could be augmented to encompass environmental effects, by assuming that energy production and manufacturing lead to local or global externalities. This would have repercussions on policy measures which are set non-cooperatively, such as tariffs in strategic trade policy. Global externalities such as climate change due to greenhouse gas emissions caused by energy production raise the question of how negotiations between energy importers and exporters over trade policies, industrial policies, and climate goals interact.

Recent crises have unveiled the vulnerability of energy-dependent manufacturing exporters to supply chain disruptions and price hikes. A version of the model with political risks might shed further light on the prospects of this "business model".

CRediT authorship contribution statement

Lutz G. Arnold: Formal analysis, Writing – original draft, Writing – review & editing. **Volker Arnold:** Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

A.1 Denote i's wage as w_i, her share in the producers' date-t profits as φ_{it}, her share in the revenue from import tariffs as ϑ_{i2}, and her date-1 savings as b_i. i chooses e_{i2} to maximize

$$u_{i2} = w_i + \varphi_{i2} + \vartheta_{i2} + (1+r)b_i - p_2 e_{i2} + \theta_i\left(\alpha_2 e_{i2} - \frac{1}{2}e_{i2}^2\right).$$

The necessary optimality condition immediately yields $e_{i2} = \alpha_2 - p_2$.

A.2 Producer j chooses x_{j2} so as to maximize

$$\pi_{j2} = [p_2 - (a_2 + q_2 + \tau_2)]x_{j2} + (q_2 + \tau_2)s_j, \tag{A.1}$$

taking q_2 and s_j ($\le x_{j2}$) as given. From (2) and symmetry, $x_{j2} = E_2/J = [(I + \theta I')/J](\alpha_2 - p_2)$. As $dp_2/dE_2 = -1/(I + \theta I')$ and $dE_2/dx_{j2} = 1$

(from $E_2 = \sum_{j=1}^{J} x_{j2}$), the perceived price change due to an increase in j's sales is

$$\frac{dp_2}{dx_{j2}} = \frac{dp_2}{dE_2}\frac{dE_2}{dx_{j2}} = -\frac{1}{I+\theta I'}. \tag{A.2}$$

So the necessary condition for profit maximization $p_2 = q_2 + a_2 + \tau_2 - (dp_2/dx_{j2})x_{j2}$ can be written as (3).

A.3 Foreign producer k's labor cost per unit of output is ωc_2, and she chooses output z_{k2} so as to maximize $\psi_{k2} = (q_2 - \omega c_2)z_{k2}$. From

$$\sum_{k=1}^{K} z_{k2} = \sum_{j=1}^{J}(x_{j2} - s_j) = E_2 - \sum_{j=1}^{J} s_j \tag{A.3}$$

and the fact that the s_j's are predetermined, $dE_2/dz_{k2} = 1$. Using (2) and (3), it follows that the export price q_2 reacts to changes in z_{k2} according to

$$\frac{dq_2}{dz_{k2}} = \frac{dq_2}{dp_2}\frac{dp_2}{dE_2}\frac{dE_2}{dz_{k2}} = -\frac{J+1}{(I+\theta I')J}. \tag{A.4}$$

So the necessary condition for profit maximization $q_2 = \omega c_2 - (dq_2/dz_{k2})z_{k2}$ can be written as

$$q_2 = \omega c_2 + \frac{J+1}{(I+\theta I')J} z_{k2}.$$

Using (2), (3), and (A.3) to eliminate z_{k2}, we obtain (4). From (2), (3), (4), and symmetry,

$$x_{j2} = \frac{(I+\theta I')K}{(J+1)(K+1)}\left[\alpha_2 - (a_2 + \tau_2 + \omega c_2)\right] + \frac{1}{K+1}s.$$

Substituting this into $x_{j2} \le s$ and solving for s yields (5).

A.4 From (3) and (4),

$$\alpha_2 - p_2 = \frac{J}{J+1}\frac{K}{K+1}\left[\alpha_2 - (\omega c_2 + a_2 + \tau_2) + \frac{J+1}{(I+\theta I')JK}\sum_{j=1}^{J} s_j\right]. \tag{A.5}$$

Using $\mathrm{var}(\alpha_2 - p_2) = \mathrm{E}[(\alpha_2 - p_2)^2] - [\mathrm{E}(\alpha_2 - p_2)]^2$, it follows that

$$\mathrm{E}[(\alpha_2 - p_2)^2] = \left(\frac{J}{J+1}\right)^2\left(\frac{K}{K+1}\right)^2\left\{\left[\bar\alpha_2 - (\omega\bar c_2 + \bar a_2 + \tau_2) + \frac{J+1}{(I+\theta I')JK}\sum_{j=1}^{J} s_j\right]^2 + \sigma^2\right\} \equiv \Psi(\boldsymbol{s}), \tag{A.6}$$

where $\boldsymbol{s} = (s_1, \ldots, s_J)$.

Substituting i's date-2 demand $e_{i2} = \theta(\alpha_2 - p_2)$ into her utility function gives her date-2 utility:

$$u_{i2} = w_i + \varphi_{i2} + \vartheta_{i2} + (1+r)b_i + \theta_i\frac{1}{2}(\alpha_2 - p_2)^2.$$

Using (A.6), expected utility is

$$\mathrm{E}u_{i2} = w_i + \mathrm{E}(\varphi_{i2} + \vartheta_{i2}) + (1+r)b_i + \theta_i\frac{1}{2}\Psi(\boldsymbol{s}). \tag{A.7}$$

A.5 Inserting $x_{j2} = [(I+\theta I')/J](\alpha_2 - p_2)$ (from (2)) and $p_2 - (a_2 + q_2 + \tau_2) = (\alpha_2 - p_2)/J$ (from (3)) into (A.1), producer j'date-2 profit can be written as

$$\pi_{j2} = \frac{I+\theta I'}{J^2}(\alpha_2 - p_2)^2 + (q_2 + \tau_2)s_j.$$

So, from (4) and (A.6),

$$\mathrm{E}\pi_{j2} = \frac{I+\theta I'}{J^2}\Psi(\boldsymbol{s}) + \left[\Phi(\boldsymbol{s}) + \tau_2\right]s_j, \tag{A.8}$$

where

$$\Phi(\boldsymbol{s}) \equiv \frac{K\omega\bar c_2 + \bar\alpha_2 - (\bar a_2 + \tau_2) - \frac{J+1}{(I+\theta I')J}\sum_{j'=1}^{J} s_{j'}}{K+1} = \mathrm{E}q_2. \tag{A.9}$$

Using

$$z_{k2} = \frac{1}{K}\left[(I+\theta I')(\alpha_2 - p_2) - \sum_{j=1}^{J} s_j\right]$$

(from (A.3)) and (A.5), producer k's date-2 profit can be written as

$$\psi_{k2} = \frac{(I+\theta I')J}{(J+1)(K+1)^2}\left[\alpha_2 - (\omega c_2 + a_2 + \tau_2) - \frac{J+1}{(I+\theta I')J}\sum_{j=1}^{J} s_j\right]^2.$$

Using (A.9), her expected date-2 profit is

$$\mathrm{E}\psi_{k2} = \frac{(I+\theta I')J}{J+1}\left\{\left[\Phi(\boldsymbol{s}) - \omega\bar c_2\right]^2 + \frac{1}{(K+1)^2}\sigma^2\right\}. \tag{A.10}$$

A.6 Consumer i's date-1 utility is

$$u_{i1} = w_i + \varphi_{i1} + \vartheta_{i1} - b_i - p_1 e_{i1} + \theta_i\left(\alpha_1 e_{i1} - \frac{1}{2}e_{i1}^2\right). \tag{A.11}$$

She chooses b_i and e_{i1} so as to maximize $u_{i1} + \beta\mathrm{E}u_{i2}$, where $\mathrm{E}u_{i2}$ is given by (A.7). The necessary conditions yield $1 = \beta(1+r)$ and $e_{i1} = \theta_i(\alpha_1 - p_1)$. Hence, $p_1 = \alpha_1 - E_1/(I+\theta I')$ and $dp_1/dE_1 = -1/(I+\theta I')$.

A.7 Producer j's date-1 profit is

$$\pi_{j1} = \left[p_1 - (a_1 + q_1 + \tau_1)\right]x_{j1} - (q_1 + \tau_1)s_j - \left[\eta + \delta(q_1 + \tau_1)\right]\frac{s_j^{\gamma}}{\gamma}. \tag{A.12}$$

She chooses x_{j1} and s_j so as to maximize $\pi_{j1} + \beta\mathrm{E}\pi_{j2}$. In doing so, she takes into account the effects of s_j on her expected date-2 profit $\mathrm{E}\pi_{j2}$, given by (A.8). Analogously to date 2, $\sum_{j=1}^{J} x_{j1} = E_1$,

$$\frac{dp_1}{dx_{j1}} = \frac{dp_1}{dE_1}\frac{dE_1}{dx_{j1}} = -\frac{1}{I+\theta I'}, \tag{A.13}$$

and $p_1 = q_1 + a_1 + \tau_1 + x_{j1}/(I+\theta I')$, so that (7) holds. The condition for optimum storage (8) follows from setting the derivative of $\pi_{j1} + \beta\mathrm{E}\pi_{j2}$ with respect to s_j equal to zero and rearranging terms. Imposing symmetry (i.e., $s_j = s$), (8) can be rewritten as

$$\lambda - (q_1 + \tau_1) - \left[\mu + \delta(q_1 + \tau_1)\right]s \le 0$$

for $\gamma = 2$ and

$$\lambda - \eta - (1+\delta)(q_1 + \tau_1) - (\mu - \eta)s \le 0$$

for $\gamma = 1$. This proves (9).

A.8 k's date-1 profit is $\psi_{k1} = (q_1 - \omega c_1)z_{k1}$. She chooses z_{k1} so as to maximize $\psi_{k1} + \beta\mathrm{E}\psi_{k2}$ at date 1. In doing so, she takes into account the impact of changes in the price q_1 induced by changes in z_{k1} on wholesalers' storage decisions (see (9)) and, hence, on date-2 expected profit $\mathrm{E}\psi_{k2}$ (see (A.10)). Using symmetry (i.e., $s_j = s$),

$$\frac{\partial(\psi_{k1} + \beta\mathrm{E}\psi_{k2})}{\partial z_{k1}} = q_1 - \omega c_1 + \left\{z_{k1} - 2\beta\frac{J}{(K+1)^2}\left[\bar\alpha_2 - (\omega\bar c_2 + \bar a_2 + \tau_2) - \frac{1}{\iota}s\right]\frac{ds}{dq_1}\right\}\frac{dq_1}{dz_{k1}}.$$

Using $\sum_{j=1}^{J} x_{j1} = E_1 = (I+\theta I')(\alpha_1 - p_1)$, the pricing rule (7), symmetry, and $\sum_{k=1}^{K} z_{k1} = \sum_{j=1}^{J}(x_{j1} + s_j + \delta s_j^{\gamma}/\gamma)$, energy producers' total sales can be expressed as

$$\sum_{k=1}^{K} z_{k1} = J\iota[\alpha_1 - (q_1 + a_1 + \tau_1)] + J\left(s + \delta\frac{s^{\gamma}}{\gamma}\right). \tag{A.14}$$

So the price change induced by a change in a producer's energy output is

$$\frac{dq_1}{dz_{k1}} = -\frac{1}{J\iota - J\left(1 + \delta s^{\gamma-1}\right)\frac{ds}{dq_1}}. \tag{A.15}$$

Changes in storage ($ds/dq_1 < 0$) dampen the impact of z_{k1} on q_1. Using (A.14) and (A.15), the necessary optimality condition $\partial(\psi_{k1} + \beta\mathrm{E}\psi_{k2})/\partial z_{k1} = 0$ can be rewritten as (11).

A.9 We proceed to show that (12) implies that $\partial(\psi_{k1}+\beta \mathrm{E}\psi_{k2})/\partial z_{k1}$ does not jump upwards at z_{k1}^0 if $z_{k1}^0 > 0$. Let all k choose the uniform quantity z_{k1} such that the necessary optimality condition (11) is satisfied. Suppose $s > 0$ and $z_{k1}^0 \geq 0$. The left-hand and right-hand derivatives of q_1 with respect to z_{k1} at z_{k1}^0 are

$$\frac{dq_1}{dz_{k1}}\bigg|^- = -\frac{1}{J\iota} \tag{A.16}$$

and

$$\frac{dq_1}{dz_{k1}}\bigg|^+ = -\frac{1}{J\iota - J\left.\frac{ds}{dq_1}\right|^-}, \tag{A.17}$$

respectively, where

$$\frac{ds}{dq_1}\bigg|^- = \begin{cases} -\frac{1+\delta}{\mu-\eta}, & \text{for } \gamma = 1 \\ -\frac{1}{\mu+\delta\lambda} & \text{for } \gamma = 2 \end{cases}$$

is (10) evaluated at q_1^0. The left-hand and right-hand derivatives of the profit function at z_{k1}^0 are

$$\frac{\partial(\psi_{k1}+\beta \mathrm{E}\psi_{k2})}{\partial z_{k1}}\bigg|^- = q_1^0 - \omega c_1 + z_{k1}^0 \frac{dq_1}{dz_{k1}}\bigg|^-$$

and

$$\frac{\partial(\psi_{k1}+\beta \mathrm{E}\psi_{k2})}{\partial z_{k1}}\bigg|^+ = q_1^0 - \omega c_1 + \left\{ z_{k1}^0 - 2\beta\frac{J}{(K+1)^2} \times \left[\bar{\alpha}_2 - (\omega\bar{c}_2 + \bar{a}_2 + \tau_2)\right] \frac{ds}{dq_1}\bigg|^- \right\} \frac{dq_1}{dz_{k1}}\bigg|^+,$$

respectively. So the derivative does not jump upwards at z_{k1}^0 exactly if

$$z_{k1}^0\left(\frac{dq_1}{dz_{k1}}\bigg|^+ - \frac{dq_1}{dz_{k1}}\bigg|^-\right) - 2\beta\frac{J}{(K+1)^2}\left[\bar{\alpha}_2 - (\omega\bar{c}_2 + \bar{a}_2 + \tau_2)\right] \times \frac{ds}{dq_1}\bigg|^- \frac{dq_1}{dz_{k1}}\bigg|^+ \leq 0.$$

From (A.16) and (A.17), the first term in parentheses on the left-hand side is positive and

$$\frac{\left.\frac{ds}{dq_1}\right|^- \left.\frac{dq_1}{dz_{k1}}\right|^+}{\left.\frac{dq_1}{dz_{k1}}\right|^+ - \left.\frac{dq_1}{dz_{k1}}\right|^-} = \iota.$$

So the inequality can be rewritten as (12).

A.10 $b_i = 0$ means that supply and demand in the loan market both equal zero. Domestic date-1 labor demand is

$$Ja_1x_{j1} + I\left[1 + \varphi_{i1} + \frac{J}{I}\tau_1\left(x_{j1} + s + \delta\frac{s^\gamma}{\gamma}\right) - p_1e_{i1}\right] + J\eta\frac{s^\gamma}{\gamma} + Jq_1\left(x_{j1} + s + \delta\frac{s^\gamma}{\gamma}\right) - I'p_1\theta e_{i1}.$$

The first three terms are the labor inputs in the production of the industrial good, domestic production of the consumption good (φ_{i1} is a domestic consumer's profit income and the subsequent term inside the square brackets is her proceeds from lump-sum distribution of the proceeds of the date-1 import tariff ϑ_{i1}), and storage, respectively. The final two terms are labor in the production of exported consumption goods. Using

$$I\varphi_{i1} = J\pi_{j1} = J\left\{\left[p_1 - (q_1 + a_1 + \tau_1)\right]x_{j1} - (q_1 + \tau_1)s - \left[\eta + \delta(q_1 + \tau_1)\right]\frac{s^\gamma}{\gamma}\right\} \tag{A.18}$$

(cf. (A.12)) and $Jx_{j1} = (I + \theta I')e_{i1}$, labor demand boils down to I, i.e., labor supply. Similarly, date-2 labor demand

$$Ja_2x_{j2} + I\left[1 + \varphi_{i2} + \frac{J}{I}\tau_2(x_{j2} - s) - p_2e_{i2}\right] + Jq_2(x_{j2} - s) - I'p_2\theta e_{i2}$$

equals I. Foreign date-1 labor demand is

$$\frac{1}{\omega}\left\{\omega I' + K\psi_{k1} - I'p_1\theta e_{i1} - \left[Jq_1\left(x_{j1} + s + \delta\frac{s^\gamma}{\gamma}\right) - I'p_1\theta e_{i1}\right]\right\} + Kc_1z_{k1}.$$

The first three terms in braces are foreign income spent on the consumption good. Subtracting imports gives domestic production. Multiplying with $1/\omega$ gives the labor input in the production of the consumption good. The final term is labor in energy production. From $\psi_{k1} = (q_1 - \omega c_1)z_{k1}$ and $J(x_{j1} + s + \delta s^\gamma/\gamma) = Kz_{k1}$, it follows that labor demand equals labor supply I'. The same holds true for date-2 labor demand

$$\frac{1}{\omega}\left\{\omega I' + K\psi_{k2} - I'p_2\theta e_{i2} - \left[Jq_2(x_{j2} - s) - I'p_2\theta e_{i2}\right]\right\} + Kc_2z_{k2}.$$

A.11 In a slight abuse of notation, rewrite $\Psi(\mathbf{s})$ as $\Psi(s)$ and $\Phi(\mathbf{s})$ as $\Phi(s)$ for an equilibrium with $\mathbf{s} = (s, \dots, s)$. From (A.7) and (A.11), a domestic consumer's equilibrium utility is

$$u_{i1} + \beta \mathrm{E}u_{i2} = 1 + \varphi_{i1} + \vartheta_{i1} - b_i - p_1e_{i1} + \alpha_1e_{i1} - \frac{1}{2}e_{i1}^2 + \beta\left[1 + \mathrm{E}(\varphi_{i2} + \vartheta_{i2}) + (1+r)b_i + \frac{1}{2}\Psi(s)\right].$$

Use $\vartheta_{i1} = \tau_1(J/I)(x_{j1} + s + \delta s^\gamma/\gamma)$, (A.18), $x_{j1} = (I + \theta I')e_{i1}/J = (I + \theta I')(\alpha_1 - p_1)/J$, and (7) to eliminate φ_{i1}, ϑ_{i1}, p_1, and e_{i1}. Use (A.8), $\vartheta_{i2} = \tau_2(J/I)(x_{j2} - s)$, $x_{j2} = (I + \theta I')(\alpha_2 - p_2)/J$, and (A.5) to eliminate $\mathrm{E}\varphi_{i2}$ and $\mathrm{E}\vartheta_{i2}$. Finally, use $1 + r = 1/\beta$ to obtain

$$\begin{aligned} u_{i1} + \beta \mathrm{E}u_{i2} = {}& 1 + \frac{(I + \theta I')J}{I(J+1)^2}[\alpha_1 - (q_1 + a_1 + \tau_1)]^2 \\ & - \frac{J}{I}\left\{(q_1 + \tau_1)s + [\eta + \delta(q_1 + \tau_1)]\frac{s^\gamma}{\gamma}\right\} \\ & + \tau_1\frac{J}{I}\left\{\frac{I + \theta I'}{J+1}[\alpha_1 - (q_1 + a_1 + \tau_1)] + s + \delta\frac{s^\gamma}{\gamma}\right\} \\ & + \frac{1}{2}\left(\frac{J}{J+1}\right)^2[\alpha_1 - (q_1 + a_1 + \tau_1)]^2 \\ & + \beta + \beta\frac{I + \theta I'}{IJ}\Psi(s) + \beta\frac{J}{I}\left[\Phi(s) + \tau_2\right]s \\ & + \beta\tau_2\frac{J}{I}\left\{\frac{(I + \theta I')K}{(J+1)(K+1)}\left[\bar{\alpha}_2 - (\omega\bar{c}_2 + \bar{a}_2 + \tau_2) + \frac{J+1}{(I + \theta I')K}s\right] - s\right\} \\ & + \beta\frac{1}{2}\Psi(s). \end{aligned}$$

Simplifying terms yields (15).

A.12 From (A.7) and (A.11), a foreign consumer's equilibrium utility is

$$u_{i1} + \beta \mathrm{E}u_{i2} = \omega + \varphi_{i1} - b_i - p_1e_{i1} + \theta_i\left(\alpha_1e_{i1} - \frac{1}{2}e_{i1}^2\right) + \beta\left[\omega + \mathrm{E}\varphi_{i2} + (1+r)b_i + \frac{\theta_i}{2}\Psi(s)\right].$$

Use $\varphi_{i1} = K\psi_{k1}/I'$, $\psi_{k1} = (q_1 - \omega c_1)z_{k1}$, (A.14), $e_{i1} = \theta(\alpha_1 - p_1)$, and (7) to eliminate φ_{i1}, p_1, and e_{i1}. Use $\varphi_{i2} = K\psi_{k2}/I'$ and (A.10) to eliminate φ_{i2}. Finally, use $1 + r = 1/\beta$ to obtain

$$\begin{aligned} u_{i1} + \beta \mathrm{E}u_{i2} = {}& \omega + \frac{J}{I'}(q_1 - \omega c_1)\left\{\frac{I + \theta I'}{J+1}[\alpha_1 - (q_1 + a_1 + \tau_1)] + s + \delta\frac{s^\gamma}{\gamma}\right\} \\ & + \frac{\theta}{2}\left(\frac{J}{J+1}\right)^2[\alpha_1 - (q_1 + a_1 + \tau_1)]^2 \\ & + \beta\omega + \beta\frac{(I + \theta I')JK}{I'(J+1)}\left\{[\Phi(s) - \omega\bar{c}_2]^2 + \frac{1}{(K+1)^2}\sigma^2\right\} \\ & + \beta\frac{\theta}{2}\Psi(s). \end{aligned}$$

Rearranging terms yields (16).

A.13 Substituting for q_1 from (13) and from the definition of $\Psi(s)$ in (A.6) into (15) yields (20) for i domestic. The corresponding expression for foreign consumers follows upon substituting $q_1 - \omega c_1 = [\alpha_1 - (\omega c_1 + a_1 + \tau_1)]/(K+1)$ and $\Phi(s) - \omega \bar{c}_2 = [\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2 + \tau_2)]/(K+1)$ into (16).

A.14 From (A.6) and (A.9),

$$\Psi(s) \to \left(\frac{J}{J+1}\right)^2 \left\{ \left[\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2 + \tau_2)\right]^2 + \sigma^2 \right\}$$

and $\Phi(s) \to \omega \bar{c}_2$. Inserting these limits and the expression for s in (14) into (15) proves the validity of (21) for domestic consumers i. The validity of (21) for foreign consumers follows from

$$\Phi(s) - \omega \bar{c}_2 = \frac{\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2) - \frac{J+1}{I+\theta I'} s}{K+1} \to 0.$$

A.15 From the definitions of Y_i and Λ,

$$\frac{\partial Y_i}{\partial \tau_1} = -2\xi_i \left[\alpha_1 - (\omega c_1 + a_1 + \tau_1)\right] < 0 \tag{A.19}$$

and

$$\frac{\partial \Lambda}{\partial \tau_1} = \frac{(I+\theta I')JK}{I(J+1)(K+1)} \left[\alpha_1 - (\omega c_1 + a_1 + 2\tau_1)\right].$$

Replacing $\alpha_1 - (\omega c_1 + a_1)$ with $\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2)$ and τ_1 with τ_2 yields the partial derivatives with respect to τ_2. For domestic consumers i, using (18),

$$\begin{aligned}
\frac{\partial(u_{i1} + \beta \mathrm{E} u_{i2})}{\partial \tau_1} &= \frac{\partial Y_i}{\partial \tau_1} + \frac{\partial \Lambda}{\partial \tau_1} \\
&= -2\left(\frac{I+\theta I'}{IJ} + \frac{1}{2}\right)\left(\frac{J}{J+1}\frac{K}{K+1}\right)^2 \\
&\quad \times \left[\alpha_1 - (\omega c_1 + a_1 + \tau_1)\right] \\
&\quad + \frac{(I+\theta I')JK}{I(J+1)(K+1)} \left[\alpha_1 - (\omega c_1 + a_1 + 2\tau_1)\right].
\end{aligned}$$

Replacing $\alpha_1 - (\omega c_1 + a_1)$ with $\bar{\alpha}_2 - (\omega \bar{c}_2 + \bar{a}_2)$ and τ_1 with τ_2 yields the partial derivative with respect to τ_2. The partial derivatives $\partial(u_{i1} + \beta \mathrm{E} u_{i2})/\partial \tau_t$ are negative evaluated at $\tau_t = 0$ $(t = 1, 2)$ exactly if

$$-2\left(\frac{I+\theta I'}{IJ} + \frac{1}{2}\right)\left(\frac{J}{J+1}\frac{K}{K+1}\right)^2 + \frac{(I+\theta I')JK}{I(J+1)(K+1)} < 0.$$

Rearranging terms yields the condition in Proposition 4. For i, foreign, $\partial(u_{i1} + \beta \mathrm{E} u_{i2})/\partial \tau_t = \partial Y/\partial \tau_t$, which is negative due to (A.19).

Utility $u_{i1} + \beta \mathrm{E} u_{i2}$ is strictly concave in τ_t $(t = 1, 2)$ exactly if

$$2\left(\frac{I+\theta I'}{IJ} + \frac{1}{2}\right)\left(\frac{J}{J+1}\frac{K}{K+1}\right)^2 - 2\frac{(I+\theta I')JK}{I(J+1)(K+1)} < 0$$

or, rearranging terms,

$$\left[\frac{2}{J+1} + \frac{IJ}{(I+\theta I')(J+1)}\right]\frac{K}{K+1} < 2.$$

As the first fraction on the left-hand side is no greater than unity, while the latter two are strictly less than unity, this inequality is satisfied.

A.16 The validity of the first claim in Proposition 5 follows from

$$\frac{\partial \xi_i}{\partial J} = \frac{I+\theta I'}{I(J+1)^3}\left(1 - \frac{\theta I'}{I+\theta I'} J\right)\left(\frac{K}{K+1}\right)^2$$

for domestic consumers i. The validity of the second claim follows from

$$\frac{\partial \xi_i}{\partial K} = \frac{(I+\theta I')(J+1)}{I' J (K+1)^3}\left[1 - \left(1 - \frac{\theta I'}{I+\theta I'}\frac{J}{J+1}\right)K\right]\left(\frac{J}{J+1}\right)^2$$

for foreign consumers i.

A.17 The price reactions to output changes are given by (A.2) and (A.13). j maximizes

$$\pi_{j1} + \pi_{j2} = [p_1 - (q_1 + a_1)]x_{j1} - q_1 s_j - \eta \frac{s_j^2}{2} + \left[p_2 - (q_2 + a_2)\right] x_{j2} + q_2 s_j,$$

given q_1, q_2, (A.2), and (A.13). Imposing symmetry, the necessary conditions for a profit maximizing choice of x_{j1} and x_{j2} can be written as (26). Eq. (27) is the necessary condition for optimum choice of s_j.

A.18 Using (27), the market clearing conditions for energy can be written as

$$\frac{\eta}{J}\sum_{k=1}^{K} z_{k1} = \iota\eta(\alpha_1 - a_1) - (\iota\eta + 1)q_1 + q_2 \tag{A.20}$$

$$\frac{\eta}{J}\sum_{k=1}^{K} z_{k2} = \iota\eta(\alpha_2 - a_2) + q_1 - (\iota\eta + 1)q_2. \tag{A.21}$$

These equations give the prices q_1 and q_2 resulting from outputs z_{k1} and z_{k2}. Differentiating with respect to one producer's outputs yields

$$\begin{aligned}
\frac{\eta}{J} dz_{k1} &= -(\iota\eta + 1)dq_1 + dq_2 \\
\frac{\eta}{J} dz_{k2} &= dq_1 - (\iota\eta + 1)dq_2.
\end{aligned}$$

Setting $dz_{k2} = 0$, we obtain

$$\frac{dq_1}{dz_{k1}} = -\frac{1}{\iota J}\frac{\iota\eta + 1}{\iota\eta + 2}, \quad \frac{dq_2}{dz_{k1}} = -\frac{1}{\iota J}\frac{1}{\iota\eta + 2}.$$

Setting $dz_{k1} = 0$, we obtain

$$\frac{dq_1}{dz_{k2}} = -\frac{1}{\iota J}\frac{1}{\iota\eta + 2}, \quad \frac{dq_2}{dz_{k2}} = -\frac{1}{\iota J}\frac{\iota\eta + 1}{\iota\eta + 2}.$$

Plugging these derivatives into the necessary conditions for profit maximization

$$\begin{aligned}
\frac{\partial(\psi_{k1} + \psi_{k2})}{\partial z_{k1}} &= q_1 - \omega c_1 + \frac{dq_1}{dz_{k1}} z_{k1} + \frac{dq_2}{dz_{k1}} z_{k2} \\
\frac{\partial(\psi_{k1} + \psi_{k2})}{\partial z_{k2}} &= q_2 - \omega c_2 + \frac{dq_1}{dz_{k2}} z_{k1} + \frac{dq_2}{dz_{k2}} z_{k2}
\end{aligned}$$

and solving for q_1 and q_2 yields (28) and (29).

A.19 A domestic consumer i's utility is

$$u_{i1} + u_{i2} = 2 + \varphi_{i1} + \varphi_{i2} + \frac{1}{2}\left[(\alpha_1 - p_1)^2 + (\alpha_2 - p_2)^2\right].$$

Using $x_{jt} = [(I+\theta I')/J](\alpha_t - p_t)$ and $\alpha_t - p_t = [J/(J+1)][\alpha_t - (q_t + a_t)]$ (for $t = 1, 2$), equilibrium profits can be written as

$$\pi_{j1} = \frac{I+\theta I'}{(J+1)^2}[\alpha_1 - (q_1 + a_1)]^2 - \left(q_1 s + \eta \frac{s^2}{2}\right)$$

and

$$\pi_{j2} = \frac{I+\theta I'}{(J+1)^2}[\alpha_2 - (q_2 + a_2)]^2 + q_2 s.$$

Eq. (30) follows from $\varphi_{it} = (J/I)\pi_{jt}$ $(t = 1, 2)$.

A foreign consumer i's utility is

$$u_{i1} + u_{i2} = 2\omega + \varphi_{i1} + \varphi_{i2} + \frac{\theta_i}{2}\left[(\alpha_1 - p_1)^2 + (\alpha_2 - p_2)^2\right].$$

Eq. (31) follows from $\varphi_{it} = (K/I')\psi_{kt}$, $\psi_{kt} = (q_t - \omega c_t)z_{kt}$ (for $t = 1, 2$), (A.20), (A.21), and (26).

Appendix B. List of symbols

Symbol	Meaning
t	Date ($\in \{1,2\}$)
I	Number of domestic consumers
I'	Number of foreign consumers
i	Index for individual consumers
c_t	Labor requirement per unit of energy produced at t (c_2 is random)
$\bar{c}_2$	Mean of c_2
ω	Reciprocal of the labor requirement per unit of the consumption good produced abroad
a_t	Labor requirement per unit produced of the industrial good (a_2 random)
$\bar{a}_2$	Mean of a_2
y_{it}	i's consumption of the consumption good at t
e_{it}	i's consumption of the industrial good (ERMI model) or energy (ECG model) at t
u_{it}	i's instantaneous utility at t ($= y_{it} + \theta_i(\alpha_t e_{it} - e_{it}^2/2)$)
θ_i	Weight of the sub-utility obtained from the industrial good or energy (=1 for domestic consumers, =0 in the ECG model and $\in \{0,1\}$ for foreign consumers)
α_t	Marginal utility of the first unit of the industrial good or of energy (α_2 random)
$\bar{\alpha}_2$	Mean of α_2
β	Subjective discount factor
K	Number of foreign energy producers
k	(also k') index for foreign energy producers
J	Number of domestic industrial goods producers or energy wholesalers
j	(also j') index for domestic industrial goods producers or wholesalers
s_j	Energy stored by j at date 1
γ	Indicator of linear (=1) or quadratic (=2) storage costs
η	Factor of proportionality for labor requirement in storage ($\eta s_j^\gamma/\gamma$)
δ	Factor of proportionality for energy requirement in storage ($\delta s_j^\gamma/\gamma$)
r	(safe) interest rate
q_t	Date-t spot price of imported energy
p_t	Date-t spot price of the industrial good
π_{jt}	Industrial good producer j's date-t profit
ψ_{kt}	Energy producer k's date-t profit
E	Expectations operator
τ_t	(specific) date-t domestic import tariff on energy
θ	Indicator of whether foreign consumers consume the industrial good (=1) or not (=0)
E_t	Total date-t energy demand
x_{jt}	Industrial good producer j's date-t output
z_{kt}	Energy producer k's date-t output
s	Storage per firm j if all choose the same amount s_j (=s)
σ^2	Variance of $\alpha_2 - (\omega c_2 + a_2)$
λ	Constant defined after Eq. (9)
μ	Constant defined after Eq. (9)
q_1^0	Value at which the function that relates s to q_1 is kinked
ι	Constant defined after Eq. (11) ($\equiv (I + \theta I')/(J+1)$)
z_{k1}^0	Energy producer k's date-1 output that leads to zero storage
$\Psi(s)$	Function defined at the beginning of Section 4 (equilibrium value of $\mathrm{E}[(\alpha_2 - p_2)^2]$)
$\Phi(s)$	Function defined at the beginning of Section 4 (equilibrium value of $\mathrm{E}q_2$)
Υ_i	Constant defined in (17), utility of a foreign consumer i in an equilibrium without storage
ξ_i	Constant defined in (18)
Λ	Constant defined in (19), additional utility of a domestic consumer i in an equilibrium without storage
η'	Factor of proportionality for labor requirement in storage ($\eta' s_j^\gamma/\gamma$) with subsidies to storage (in Section 7)
δ'	Factor of proportionality for energy requirement in storage ($\delta' s_j^\gamma/\gamma$) with subsidies to storage (in Section 7)
Ω	Constant defined in (25), lump-sum tax that yields a balanced budget
q_2	In Section 8: price, specified in a long term contract, of one unit of energy delivered at date 2

Country codes in Fig. 1:

BWA (Botswana), ISR (Israel), CHN (China), HKG (Hong Kong), CZE (Czech Republic), KHM (Cambodia), SVK (Slovakia), IRL (Ireland), KOR (South Korea), HUN (Hungary), JPN (Japan), DEU (Germany), VNM (Viet Nam), SVN (Slovenia), MKD (North Macedonia), LUX (Luxembourg), ROU (Romania), ITA (Italy), TUN (Tunisia), PHL (Philippines), AUT (Austria, FRA (France), MEX (Mexico), POL (Poland), TUR (Turkey)

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