

# How does the price of electricity affect imports? A study of Swedish manufacturing firms\*

## Working Paper

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### Abstract

This paper examines the heterogeneous effects of a domestic electricity price increase on the structure of imports. We develop a simple analytical model of heterogeneous firms, which predicts that higher electricity prices lead firms to increase their demand for imported intermediate inputs. At the same time, we predict that higher electricity prices lead firms to increase their demand for electricity intense imports. The model is estimated using detailed firm level data for Swedish manufacturing that includes the products they import, over the years 1997-2007 inclusive. Our identification strategy uses variation in the price of Swedish electricity to estimate how the structure of electricity intense imports respond at the firm level. Our empirical results identify the magnitude of the impact of the electricity price increase on the structure of firm imports. Our findings agree with the predictions of our theoretical model.

*JEL Classification:* D21, D22, F12, F14, Q40

*Keywords:* Firm heterogeneity, electricity, imported intermediate inputs

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# 1 Introduction

In many economies, electricity supply and consumption is already undergoing a fundamental shift and more change is necessary if ambitious policy objectives are to be realized. The potential restriction in energy supply facing the German and Japanese economies as Nuclear facilities are taken offline could impose profound changes to their energy systems. Switzerland intends to follow suit.<sup>1</sup> Furthermore, energy infrastructure in general will need to be restructured if ambitious commitments to reduce greenhouse gas emissions within the next decades are realized, which may lead to higher prices for electricity.<sup>2</sup> There is also an international dimension. On the one hand, energy policies vary from country to country and common objectives are often pursued with differing levels of ambition. On the other hand there is genuine concern that increasingly open global markets are putting pressure on energy and electricity intense industries facing competition from abroad. However, there is a dearth of evidence on how firms and their engagement in international markets, responds to higher energy prices.

The contribution of this paper is to examine, both theoretically and empirically, the heterogeneous effects of a domestic energy price increase on the structure of imports at the firm level. We seek to identify the *magnitude* of the impact an electricity price increase has on the level of imports at the firm level. We begin by developing a simple analytical model of heterogeneous firms that incorporates trade in intermediate inputs. The focus of our study is trade in intermediate inputs; trade in final goods is not part of the scope. The model builds on work by (Melitz 2003), extended to allow trade in intermediate inputs by (Kasahara and Lapham 2008). The theory illustrates how higher electricity prices induce firms to import electricity-intensive intermediates that have become relatively expensive to purchase at home. The incentive to source intermediates abroad is increasing in products that embody large amounts of electricity as a share of their value.

Our identification strategy uses variation in Swedish electricity prices to estimate how the structure of electricity intense imports respond at the firm level. We test the hypotheses derived from our theory with a rich data set covering Swedish manufacturing sectors over the period 1998-2007. During this time period the domestic price of electricity in Sweden for industrial consumers suddenly increased after a long period of declining prices. Sweden faced relatively low prices until 2002, but Swedish prices abruptly converged to the higher level of Germany and the EU15 average from 2003 and onward. A distinctive feature of the data is the availability of foreign inputs at the product level for individual firms and the electricity bill paid by each firm. This level of detail makes it possible to construct a highly disaggregated picture of the domestic electricity use avoided by a firm through the use of foreign intermediate inputs and enables us to disentangle the effects that determine a firm's import decision, and to identify the impact of

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<sup>1</sup><http://www.bfe.admin.ch/themen/00526/00527/index.html?lang=en>

<sup>2</sup>The USA has committed to reduce greenhouse gas emissions by 17% from 2005 levels by 2020, and the EU has pledged a reduction of between 20-30% from 1990 levels by 2020. See [http://unfccc.int/meetings/copenhagen\\_dec\\_2009/items/5264.php](http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php)

the electricity price increase.

We find evidence that higher electricity prices lead firms to *significantly* increase their relative use of imported intermediate inputs and that imports are increasing in the electricity intensity of the products imported. These results agree with the predictions of our theoretical model.

The paper continues with a description of the Swedish electricity market in Section 2. The theoretical model is presented in Section 4. The data and descriptive statistics are explained in Section 5. The empirical specification is described in Section 6 and the Results are presented and discussed in Section 7. Section 8 concludes.

## 2 The Swedish Electricity Market

In terms of per capita usage, Sweden is one of the most electricity intense economies with only Iceland, Norway, Canada and Finland ranking higher. This is due to several factors; the Swedish economy's relatively large share of electricity intense industrial production, a colder climate and historically low electricity prices, which have provided an incentive to use electricity as a source of energy in domestic and industrial use. The USA, in contrast has a per capita electricity use that is 10% lower than Sweden's, and the EU15 are on average 54% lower. In 2008, Swedish hydropower met 47% of Swedish electricity demand whereas nuclear power met 42%. The remaining 11% were produced using fossil fuels and biofuels. Sweden participates in the Scandinavian electricity market, which provides electricity users the opportunity to choose where they buy their electricity.

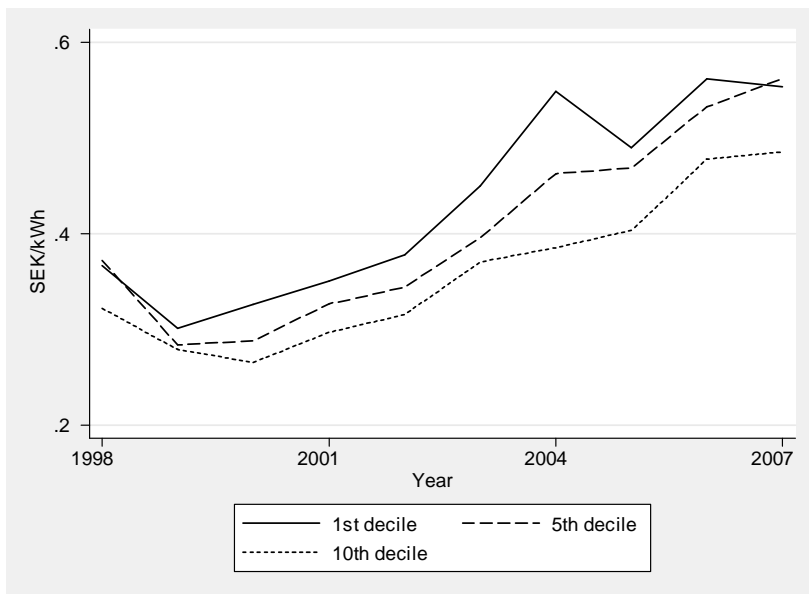
About a third of Swedish industrial energy use in 2008 was electricity. The top six sectors, defined at the 2 digit level, accounted for around 88% of industrial electricity use (in 2008) with the pulp, paper and paper products sector accounting for approximately 33-40% of industrial electricity use over the period from 1998-2008.<sup>3</sup> At the same time there is significant variation across each of these sectors in terms of their electricity intensity.

Electricity prices prior to 2002 were low relative to continental Europe. The price of electricity increased in 2003, converging towards levels paid in Germany and other European countries. This sustained increase in prices, illustrated in Figure 2, was caused by several factors. Electricity markets in Scandinavia became more closely integrated with those of continental Europe, which led to a convergence in prices. The sudden increase in prices, however, was most likely triggered by the particularly dry summer of 2002, which led to decreased hydropower production and high electricity prices in the winter of 2003. Levels in the hydropower magazines did not return to normal until the end of 2004. The introduction of the European Union's Emission Trading system; a policy initiative to tackle emissions that cause climate change, likely had an impact on electricity prices. The introduction of tradeable emissions permits was intended to

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<sup>3</sup>The next two most important sectors are basic metals with approximately 13-20%, and chemicals and chemical products with approximately 12-18% shares respectively. These figures are obtained from our data, which we will discuss shortly. The sectors are defined at the 2 digit level.

increase the cost of producing greenhouse gas intense energy. Swedish electricity production is dominated by low emission technology, namely hydropower and nuclear power, however the introduction of the EU's climate policy may have affected the relative price of electricity and other, more emissions intense, energy sources. Sorting out the impact of the EU ETS on the Swedish electricity market is a research question in its own right but some suggest that the price of emissions permits has had a significant impact on the price of electricity in the Nordic countries. Another confounding factor was sporadic closures of nuclear power production.



Prices paid by manufacturing firms from 1998-2007, by price decile in 2002.

Demand for electricity changed over this period, which may have also affected price of electricity in Sweden. During the 1998-2007 period, the Swedish economy was growing steadily. Swedish GDP grew at 2.5% in 2002, 2.3% in 2003 and 4.2% in 2004. Changes in demand facing the firm is therefore also expected to be a determinant of the impact of higher electricity prices on firm behavior.

### 3 Related Literature

Trade in intermediate inputs is significant and growing and is now a salient feature of international production. Economic research efforts match this trend and there is a sizeable literature examining the economic impact of a change in the relative price of imports. The theory we develop extends the trade models of heterogenous firms (à la (Melitz 2003)) to include costly trade in, and production with, imported intermediate goods. In particular our theory draws on the contribution by (Kasahara and Lapham 2008). They show that lowering tariffs on imported intermediate inputs can have substantial aggregate productivity and welfare gains. In their

approach firms can, in addition to serving the domestic market, export final goods, import intermediate inputs or do both. Increasing returns to scale production technology deployed by firms means that accessing markets from abroad (for sales of final goods and purchasing intermediate goods) boosts firm productivity. Thus the demand for imported intermediates is partly derived from the "love of variety" in production but also from a change in the tariff applied to imports. Another study that has drawn on this approach is (Amiti and Davis 2012). They study the impact of trade liberalization on the wages paid by firms. Trade liberalization is shown to increase wages most for those working at the most international firms; those firms that are engaged in both exporting and importing. Unlike these studies, our model examines how imports are used by some firms to mitigate a domestic cost shock. Thus the demand for imported intermediates is partly derived from the "love of variety" in production as in (Kasahara and Lapham 2008) but also from the change in the price of electricity at home relative to abroad.

International trade in intermediate goods, equated by some with the term offshoring, has been studied in a neo-classical general equilibrium setting by (Grossman and Rossi-Hansberg 2008). They extend the Heckscher-Ohlin trade model to incorporate a technology where tasks necessary for the production of a final good can be moved offshore. Their general equilibrium approach requires factor prices to be determined endogenously, and is therefore not applicable to study the issue that is the focus of our study, which is essentially an increase in a factor price that is exogenous to the model.

A variation in the exchange rate has also been used as a way to identify the trade impact of a change in the relative price of imports. In the face of an real exchange rate shock Swedish importers and exporters shed labour however only the exporters increased labour productivity according to (Ekholm, Moxnes, and Ulltveit-Moe 2011). (Tomlin 2010) also studies the effect of real exchange rates on export behavior. (Schmitz Jr 2005) studies the impact of imports of low-cost Brazilian iron ore at on the U.S.-Canada Iron Ore sector in the 1970's. In response to this shock, labour productivity in the sector doubled. In contrast, the focus of our study is on the impact of an increase in a domestic factor price on the firm's choice to employ imported inputs in production.

## 4 Theoretical Model

The model examines the use of imported intermediate inputs in production where firms are subject to an exogenous domestic electricity price increase. Firms make their decisions contingent on this price. The economy consists of a monopolistic competitive industry (manufacturing) that is engaged in the production of differentiated goods under increasing returns. Firms are heterogeneous in productivity and face fixed importing costs, analogous to the fixed cost for exporting deployed by (Melitz 2003). In our model there is no exporting activity.

Consumer preferences over manufactured goods are CES from (Dixit and Stiglitz 1977).

Consumers allocate revenue  $R$  across varieties  $i \in \Omega$  to solve

$$\min R = \sum_{i \in \Omega} p_i c_i \text{ s.t. } U_j \geq \left( \int_{i \in \Omega} c_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}$$

where  $\sigma > 1$  is the elasticity of substitution between final good varieties,  $p_i$  is the consumer price of variety  $i$  and  $c_i$  is the quantity of variety  $i$  demanded. Solving the consumer's problem yields the demand curves for each variety  $i$

$$c_i = \frac{p_i^{-\sigma}}{P^{1-\sigma}} R. \quad (1)$$

where  $P \equiv \left( \int_{i \in \Omega} p_i^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$  is the price index of manufacturing goods.

The production side of the model is derived from (Kasahara and Lapham 2008). In our set up, firms must pay a fixed cost  $F$  to enter the manufacturing sector. After having sunk  $F$ , the firm observes its own electricity efficiency coefficient  $\varphi_i$  drawn from a cumulative distribution  $G(\varphi_i)$ . Once firms observe their productivity draw they have the option to exit the market and therefore not engage in any production. If the firm does choose to produce, it must bear an additional fixed cost  $f$ . This allows the firm to access domestic intermediate inputs for production. If the firm wants to access *imported* intermediate inputs for production, then it must incur an additional fixed cost  $f_m$ ; that is a beachhead cost for importing intermediates. There are thus two types of firms active in the market; type-D are those firms that use only domestic intermediate inputs and type-M are those firms that also employ imported intermediate inputs. The production technology therefore exhibits variable and fixed cost components.

The production of intermediate intermediate inputs is undertaken by  $N$  domestic and  $N^*$  foreign firms indexed with  $j$  and  $q$  respectively. Production follows a Cobb-Douglas technology that combines electricity  $e$  with some non-electric factor  $k$  to produce a quantity of intermediate inputs

$$\begin{aligned} x^o(j) &= e(j)^\delta k(j)^{1-\delta} \\ x(q) &= e(q)^\beta k(q)^{1-\beta}. \end{aligned}$$

$\delta$  captures the share of electricity used in production at home whereas  $\beta$  captures the same for production abroad. A domestic (foreign) firm pays a price  $\rho$  ( $\rho^f$ ) for electricity and 1 for the factor  $k$ . The firm's cost minimization problem at home and in foreign is

$$\begin{aligned} \min_{e(j), k(j)} C(e(j), k(j)) &= \rho e(j) + k(j) \\ \text{such that } 1 &\geq e(j)^\delta k(j)^{1-\delta} \end{aligned}$$

$$\begin{aligned} \min_{e(q), k(q)} C(e(q), k(q)) &= \rho^f e(q) + k(q) \\ \text{such that } 1 &\geq e(q)^\beta k(q)^{1-\beta} \end{aligned}$$

The solution yields  $p_{x^o}$  and  $p_x$ , which are the prices of each domestic and foreign intermediate variety. We express this as the ratio

$$\frac{p_{x^o}}{p_x} = \frac{\frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}} (\rho)^{\delta}}{\frac{\beta^{-\beta}}{(1-\beta)^{1-\beta}} (\rho^f)^{\beta}}. \quad (2)$$

Intermediate varieties are used as inputs to the production of a final good, undertaken by a firm denoted by subscript  $i$ , which produces a quantity  $X$  with a Cobb-Douglas technology by combining electricity  $l_i$  with quantities of domestic intermediate inputs  $x^o(j)$  and, for type-M firms, quantities of imported intermediate inputs  $x(q)$

$$X(\varphi_i, m_i) = \varphi_i l_i^\alpha \left[ \int_0^N [x^o(j)]^{\frac{\gamma-1}{\gamma}} dj + m_i \int_0^{N^*} (x(q))^{\frac{\gamma-1}{\gamma}} dq \right]^{\frac{(1-\alpha)\gamma}{\gamma-1}}.$$

$\varphi_i$  is a parameter capturing the productivity of the firm. We designate this as the firm's in-house productivity, which can be augmented by buying intermediate inputs. This productivity augmentation is driven by the increasing returns to variety in the assembly of intermediate inputs, which is a result of the CES production in the square brackets. Firms can substitute intermediate inputs in production with a constant elasticity  $\gamma > 1$ ; a wider variety of intermediate inputs augments total factor productivity. In this setting, the term variety refers to horizontally differentiated products.<sup>4</sup>  $m_i = (0, 1)$  is a binary variable, which assumes a value of 1 for a type-M firm.  $\alpha \in (0, 1)$  is the Cobb-Douglas output elasticity of the in house electricity use  $l_i$ , which is supplied at a price  $\varepsilon_i$ .  $1 - \alpha$  is the share of intermediate inputs used in the production of the final good. Each firm  $i$  has access to  $N$  domestic intermediate varieties, and demands a quantity  $x^o(j)$ . Only type-M firms have access to  $N^*$  imported intermediate varieties  $x(q)$ .

We consider the impact of a change in the domestic electricity price to the equilibrium, the model is solved contingent electricity prices paid at home and in foreign; a firm's cost minimization problem is solved taking the electricity price as given.

The problem facing the firm producing the final good is therefore

$$\begin{aligned} \min_{l_i, x_i, x_i^o} C(l_i, x_i, x_i^o) &= \varepsilon_i l_i + p_{x^o} x^o(j) + p_x x(q) \\ \text{such that } 1 &\geq \varphi_i l_i^\alpha \left[ \int_0^N [x^o(j)]^{\frac{\gamma-1}{\gamma}} dj + m_i \int_0^{N^*} (x(q))^{\frac{\gamma-1}{\gamma}} dq \right]^{\frac{(1-\alpha)\gamma}{\gamma-1}} \end{aligned}$$

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<sup>4</sup>This approach is also used by (Kasahara and Lapham 2008) although the use of his class of production technology follows from earlier work in macroeconomics, growth and international economics. See for example (Grossman and Helpman 1991) and Ethier (1987).

In equilibrium, a final goods producer will employ the same quantity of each domestic intermediate, thus

$$\begin{aligned}x^o(j) &= x^o \text{ for all } j, \text{ and} \\x(q) &= x^o \text{ for all } q, \text{ and}\end{aligned}$$

Cost minimization implies that type-M firm demand for imported intermediates can be expressed as a function of the demand for domestic intermediates

$$\frac{x_i}{x_i^o} = \left( \frac{p_{x^o}}{p_x} \right)^\gamma. \quad (3)$$

Equation 3 reveals that, relative to the demand for domestic varieties, the demand for imported intermediates increases in the price of domestic varieties, which is a function of  $\rho$ , the electricity price paid by domestic intermediate firms and also the substitutability of intermediate inputs  $\gamma$ . Likewise, equilibrium demand for electricity by firm  $i$  is

$$l_i = \frac{\alpha}{\varepsilon_i(1-\alpha)} x_i^o \left( \frac{p_{x^o}}{p_x} \right) \left[ N + m_i N_i^* \left( \frac{p_{x^o}}{p_x} \right)^{\gamma-1} \right].$$

A firm's output can therefore be expressed as

$$X(\varphi_i, m_i) = \varphi_i \lambda_i l_i^\alpha \left[ \left( N + m_i N_i^* \left( \frac{p_{x^o}}{p_x} \right)^{\gamma-1} \right) x_i^o \right]^{(1-\alpha)}$$

where

$$\lambda_i \equiv \left[ N + m_i N_i^* \left( \frac{p_{x^o}}{p_x} \right)^{\gamma-1} \right]^{\frac{1-\alpha}{\gamma-1}}$$

is a productivity enhancement term capturing two effects. The first is the productivity benefit of using a wider variety of intermediate inputs;  $\lambda_i$  is increasing in both  $N$  and  $N_i^*$  which is derived from the love of variety effect, which is a characteristic of the production function employed here. The second is from a change in  $\frac{p_{x^o}}{p_x}$  suggesting that an increase in the relative price of a domestic intermediate inputs leads to an increase in the benefit from using imported intermediates. Firm productivity is therefore the product of a distribution of in-house productivities  $\varphi_i$  and a distribution productivity enhancements from importing  $\lambda_i$ , which is a function of  $\frac{p_{x^o}}{p_x}$ .

Having observed their productivity draw, firms follow a decision process where they maximize profit contingent on electricity prices. Each firm operates under increasing returns to scale at the plant level, and following (Dixit and Stiglitz 1977), we assume there to be a large number of monopolistically competitive firms in the manufacturing sector. The elasticity of demand  $\sigma$  is therefore equal to the elasticity of substitution between any pair of differentiated goods.



Firm's set prices as a function of the firm's marginal cost

$$p_i = \frac{\sigma}{\sigma - 1} \frac{1}{\Gamma \varphi_i \lambda_i}$$

where  $\Gamma \equiv \alpha^\alpha (1 - \alpha)^{1-\alpha}$  is a parameter that characterizes the energy intensity of the sector. This pricing rule is analogous to (Melitz 2003). Revenue for the firm is therefore

$$r_i = R \left[ \frac{\sigma}{\sigma - 1} \frac{1}{P \Gamma \varphi_i \lambda_i} \right]^{1-\sigma}$$

where  $R = P_j C = \int_{i \in \Omega} r_i di$  is aggregate income equal to total expenditure. The profits of type-D and type-M firms are therefore

$$\begin{aligned} \pi(\varphi_i, 1) &= \frac{r_i}{\sigma} - f_m - f \\ \pi(\varphi_i, 0) &= \frac{r_i}{\sigma} - f \end{aligned}$$

respectively. Rewriting these expressions we get

$$\begin{aligned} \pi(\varphi_i, 1) &= B \left[ \frac{1}{\varphi_i \lambda_i} \right]^{1-\sigma} - f_t \\ \pi(\varphi_i, 0) &= B \left[ \frac{1}{\varphi_i \lambda_i} \right]^{1-\sigma} - f \end{aligned}$$

where  $B \equiv \frac{R}{\sigma} \left[ \frac{\sigma}{P(\sigma-1)\Gamma} \right]^{1-\sigma}$  and  $f_t \equiv f_m + f$ . Analytical solutions to the macroeconomic variables ( $\varphi_M, \varphi_D$  and  $P^{1-\sigma}$ ) are provided in the appendix. With these results we can derive an expression that describes firm demand for intermediate inputs. Demand for final good  $i$  must equal output from firm  $i$  recalling there is no international trade in final goods. Hence

$$x_i^o = \left( \frac{p_{x^o}}{p_x} \right)^{-\alpha} \frac{(\lambda_i \varphi_i)^{\sigma-1}}{N + m_i N^* \left( \frac{p_{x^o}}{p_x} \right)^{\gamma-1}} \frac{R}{\Theta P^{1-\sigma}} \quad (4)$$

$$x_i = \left( \frac{p_{x^o}}{p_x} \right)^{\gamma-\alpha} \frac{(\lambda_i \varphi_i)^{\sigma-1}}{N + m_i N^* \left( \frac{p_{x^o}}{p_x} \right)^{\gamma-1}} \frac{R}{\Theta P^{1-\sigma}} \quad (5)$$

where  $\Theta \equiv \left( \frac{\sigma}{\Gamma(\sigma-1)} \right)^\sigma \left( \frac{\alpha}{1-\alpha} \right)^\alpha$ . A change in  $\frac{p_{x^o}}{p_x}$  affects firm level demand for imported intermediate inputs  $x_i$  in several ways. First is the direct reduction in cost resulting from avoided domestic electricity prices. This is captured by  $\left( \frac{p_{x^o}}{p_x} \right)^{\gamma-\alpha}$ . Second, importing allows type-M firms to keep marginal costs down resulting in increased demand for their final good, which in turn increases the demand for imports. This is captured by the term  $(\lambda_i \varphi_i)^{\sigma-1}$ . Third is the fall in imports resulting from increased productivity from intermediate inputs; the pro-

ductivity benefits of variety are enhanced by  $\frac{p_{x^o}}{p_x}$ . This is captured by the denominator term  $N + m_i N^* \left(\frac{p_{x^o}}{p_x}\right)^{\gamma-1}$ . Thus a price increase serves to both drive an increase in the demand for imports, but at the same time enhances the productivity benefit of importing, which serves to decrease the demand for imports. Finally, a change in  $\frac{p_{x^o}}{p_x}$  affects the price index  $P^{1-\sigma}$ . We would expect that an increase in the price of electricity would result in higher price levels. This suggests  $\frac{\partial P^{1-\sigma}}{\partial \left(\frac{p_{x^o}}{p_x}\right)} > 0$ . Together this suggests a change in  $\frac{p_{x^o}}{p_x}$  affects demand for  $x_i$  via several channels that can confound each other. We therefore derive our first testable hypothesis from equation (3), which we summarize with the following proposition.

**PROPOSITION 1** *Relative to a firm's demand for domestic varieties, demand for imported intermediates increases in the price of electricity paid by . Firms that can substitute more easily between intermediate varieties will import more.*

If the firm can substitute easily between intermediate varieties, then the firm can use imports (of embodied electricity) to mitigate the impact of an increase in  $\frac{p_{x^o}}{p_x}$  on the cost of production, which allows it to maintain revenue.

Our theory also suggests that firm's that use a higher share of electricity in production will demand more electricity intense imports. Substituting equation (2) into equation (3) yields

$$\frac{x_m}{x_m^o} = \left( \frac{\frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}} (\rho)^\delta}{\frac{\beta^{-\beta}}{(1-\beta)^{1-\beta}} (\rho^f)^\beta} \right)^\gamma.$$

Taking the logs of both sides and taking the partial derivative with respect to the log of the price paid by the domestic intermediate firm  $\ln(\rho_m)$  yields

$$\frac{\partial \ln \left( \frac{x_m}{x_m^o} \right)}{\partial \ln(\rho_m)} = \delta \gamma > 0.$$

This leads to a second empirically testable proposition.

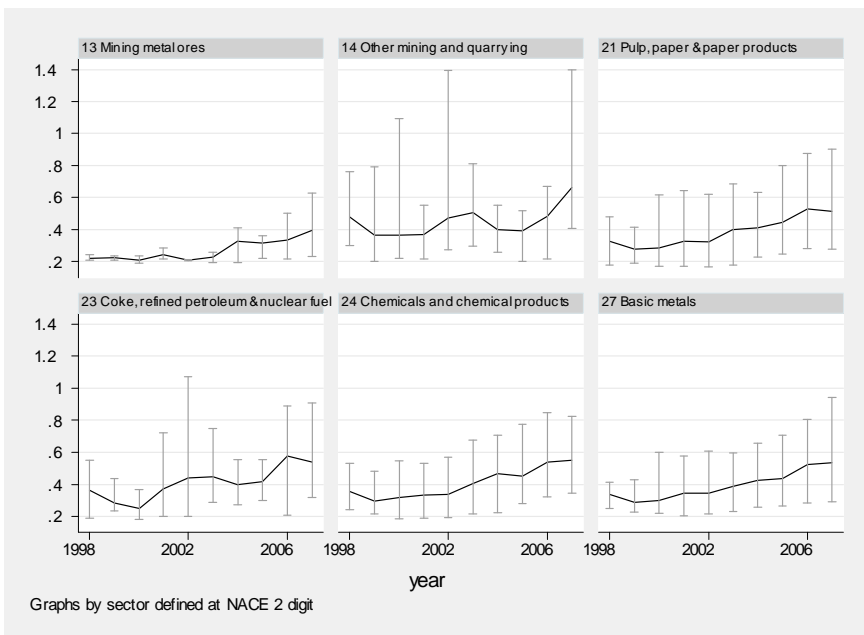
**PROPOSITION 2** *Firms import more electricity intense intermediate varieties as the domestic price of electricity increases.*

## 5 Data and Descriptive Statistics

The data we analyze was obtained from the Swedish Survey of Manufacturers conducted by Statistics Sweden, the Swedish government's statistical agency. We use data for 1998-2007, which covers 4194 firms (4-digit NACE rev.1.1 codes 10.30-37.20) with 10 or more employees and 119 import products . The survey contains information on output, value-added, employment, capital stocks, investment and value of raw materials that allow for the calculation of total factor

productivity at the firm level. We merge this data with customs data on firm-level imports from the rest of the world, which we aggregate to the 6-digit Common Nomenclature (CN) level. We deflate the import data using 2-digit CN product-specific price indices in order to control for fluctuations in import values over time that are not driven by a general change in the price of imported goods.

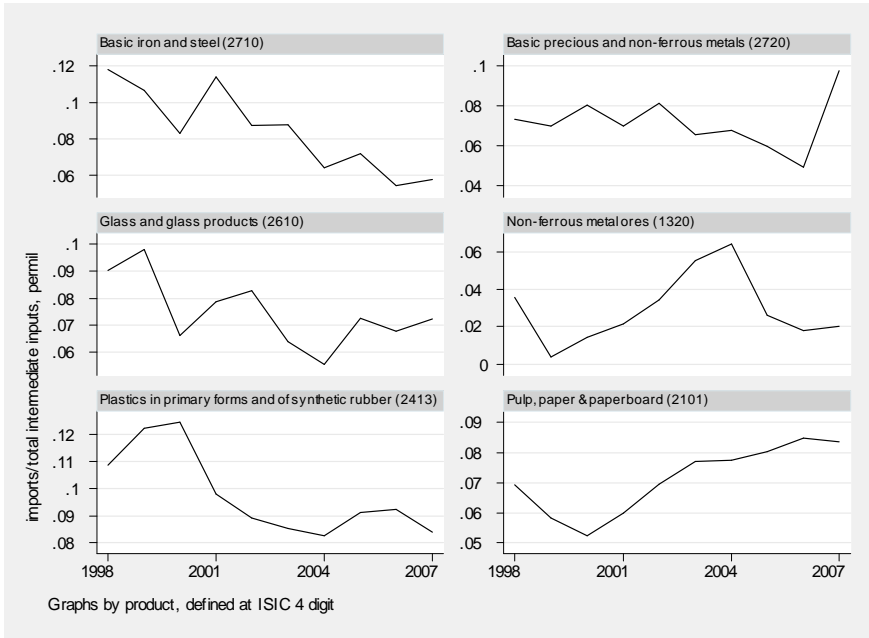
The electricity data also comes from Statistics Sweden and includes the quantity, value and average price of electricity paid each year. The energy survey was a random sample of firms in 1998-1999 but was expanded to cover all manufacturing firms with more than 10 employees from the year 2000 onwards. The electricity data is available at the plant level but we aggregate it to the firm level in order to match with the import data, which is available only at the firm level. The distribution of electricity prices paid by six electricity intense sectors, defined at the two-digit NACE level, are presented in figure 5. This figure illustrates that electricity prices increased slowly on average but the variation in prices increased dramatically in 2003.



Electricity price distribution by two-digit industry classification showing the mean electricity price in SEK/KWh and the 5th and 95th percentile limits.

One challenge is to find a variable that captures the share of electricity embodied in imports of intermediate inputs for narrowly defined products. We use the share of electricity embodied in Swedish outputs as our proxy for the share of electricity embodied in imports. This proxy represents the opportunity cost to produce or buy the input domestically instead of importing from abroad. We first define the share of electricity embodied in outputs as the ratio of electricity (in kilowatt hours) per kronor output. The electricity intensity of each firm is derived using the 4-digit NACE rev. 1.1, which we use to define the average of a firm's electricity intensity in each industry for the years 1998-2000. We build two concordances to calculate the electricity

intensity at the product level. The first concordance matches each firm identified by the 4-digit NACE rev. 1.1 industry code to the products they produce defined by the unique 4-digit ISIC rev.3.1 code. The second concordance matches the domestic product data with the imported product data by using a the concordance between the 6-digit CN and the 4-digit ISIC rev. 3.1 code. The value of electricity embodied in imports for a handful of electricity intense sectors is summarized in figure 5.



The value of imported electricity embedded in imported products by two digit sector, defined by 4-digit NACE rev. 1.1.

Tariffs have, understandably, played a role in determining firm demand for imported intermediate inputs. Therefore we control for changes in tariff rates imposed on foreign imports. Sweden joined the European Union in 1995 and the tariffs have since then been set in Brussels. This mitigates, to a degree, the chance that Swedish industry has exerted significant influence on tariff rates. We match tariff data from UNCTAD TRAINS, which is at a six-digit HS96 and HS02 level, to our firm level import data that is coded to six-digit CN. Our tariff measure is firm-specific, weighted by the relative value of imports from each country each year. Table 1 summarises the descriptive statistics of the key variables used in the analysis.

Table 1: Descriptive statistics

Variable	obs.	mean	std. dev	min	max
Imports/total inter. inputs	65438	0.0028%	.0002647	0	5.78%
Intermediate inputs	65438	41246 MSEK	170232	-160609 MSEK	4353002
Imported products	65438	4.6 MSEK	53.05	0	4654.8 MSEK
Raw material inputs	65438	436559 MSEK	1128958	-2114 MSEK	16600000 MSEK
Electricity price	65438	0.39 SEK/KWh	0.195	0.099 SEK/KWh	7.94 SEK/KWh
Weighted tariff	65438	0.63%	1.67	0	52.55%
Productivity	64850	23.79	25.02	0	247.95
Electricity Intensity, output	60860	0.069	0.185	-0.57	4.98
Electricity Intensity, imports	65438	0.044	0.048	0.0036	1.37

## 6 Empirical Specification

We use heterogeneity in firm exposure to the electricity cost shock to investigate the impact on firm level demand for imported intermediate inputs. This is a key feature of our identification strategy.

The model generates two hypotheses on how the electricity cost shock will affect firm demand for imported intermediates. Taking the natural log of equation (3) and adapting for the product  $p$ , firm  $i$  and year  $t$  structure of our data yields our benchmark equation

$$\ln SM_{ipt} = \gamma_o + \gamma_t + \gamma_1 \ln EP_{it} + \gamma_2 I_{ipt} + \varepsilon_{it} \quad (6)$$

The dependent variable is defined as

$$SM_{ipt} \equiv \frac{x_{ipt}}{x_{it}^o},$$

which is the ratio of the value of imported and domestic inputs by product  $p$  for a firm  $i$  in year  $t$  in Swedish Crowns (SEK). The data reveals that firms import not only intermediate inputs but also a significant amount of final goods.<sup>5</sup> This means that there are instances where the value of a firm's imports exceed the value of intermediate goods used in production. We are interested in the trade of intermediate inputs for production and therefore restrict our data

<sup>5</sup>This is a characteristic of international trade that is documented by (Bernard, Blanchard, Van Beveren, and Vandenbussche 2012).

to include imported products that are classified as an input to production.<sup>6</sup> This ensures our dependent variable  $SM_{ipt}$  is positive.

The focus is on two independent variables. The first variable of interest is  $EP_{it}$ , which is the average annual electricity price paid by firm engaged in the production of the final good, calculated using the electricity bill and the quantity of electricity used by each firm in a given year. We do not observe the electricity price paid by the producer of the intermediate variety. We therefore use the electricity price paid by final good producer as a proxy. By proposition (1), we expect the sign of the coefficient to be positive, an increase in the price of electricity leads to an increase in  $SM_{ipt}$ .

The second variable of interest is  $I_{ipt}$ , which captures the electricity intensity of the imported product (estimated from ISIC rev 3.1 at the six digit product code). The estimated coefficient on this variable tests proposition (2) and we expect a positive sign. We define

$$I_{ipt} \equiv \frac{E_{ip}}{L_{ipt}}$$

where  $E_{ip}$  describes the units of electricity used in the production of an imported product define using year 1998-2000 statistics. This is estimated from the electricity used by swedish manufacturers of these products, which we can obtain from our dataset.  $L_{ipt}$  is the value of other all raw inputs (excluding electricity) used in the production of this product. This interaction therefore results in a variable, with units of SEK per kWh, that captures the electricity intensity of a product produced in Sweden.

Where indicated, we estimate the equation using ordinary least squares with firm fixed effects  $\gamma_o$ , to control for unobserved firm-level heterogeneity year fixed effects  $\gamma_t$  to control for trends across time. One issue, discussed already in the development of the theory, is the effect of the electricity price increase on demand for intermediate goods via the price index. While this effect works counter to the mechanisms we are estimating, the use of year fixed effects should mitigate the price index channel.

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<sup>6</sup>We use EUROSTAT's end-use categories based on the NACE rev.2 classification defined in 2007 to distinguish intermediate inputs from final good imports.

## 7 Results

Table 1 reports the results of our estimation of equation (6). The dependent variable "import intensity", defined as the the ratio of imports to total intermediate inputs used in production. The estimates can be interpreted as elasticities by virtue of the logged dependent and independent variables.

Table 1: Electricity prices and Imports

	(1)	(2) year	(3) ind+year	(4) firm+year
Ln elec. price	1.082 (0.097) <sup>***</sup>	1.825 (0.125) <sup>***</sup>	1.422 (0.110) <sup>***</sup>	0.091 (0.037) <sup>**</sup>
Ln elec. intensity imports	0.973 (0.157) <sup>***</sup>	0.972 (0.156) <sup>***</sup>	0.984 (0.159) <sup>***</sup>	0.870 (0.136) <sup>***</sup>
tariff	-0.121 (0.020) <sup>***</sup>	-0.163 (0.019) <sup>***</sup>	-0.172 (0.020) <sup>***</sup>	-0.192 (0.020) <sup>***</sup>
Observations	65438	65438	65438	65438
R <sup>2</sup>	0.087	0.101	0.092	0.071

Standard errors in parentheses

Dependent variable: logged ratio of value of ISIC rev.3.1 product p imports and total firm intermediate inputs by firm i in year t.

Fixed effects stated at top of each column.

\*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Column (1) summarizes the results from a pooled regression. The results identify the effect of electricity prices across all firms in all sectors over the course of the sample period. The coefficient indicates that a 1% increase in electricity prices leads a 1.1% increase in import intensity, statistically significant to the 1% level. We find that import intensity is also significantly affected by its electricity intensity; firms increased their imports of intermediates more for goods with a high electricity intensity. Finally, variation in the level of tariffs across all firms decreased imports.

The regression in column (2) introduces year dummies, which control for the price of other inputs and raw materials that vary from year to year and may also affect importing behavior. Adding the year dummies changes the interpretation of the price coefficient, since it captures price deviations from the average price within each year. The results are robust to adding the year dummies.

Industry dummies are added in column (3), which controls for systematic differences in import intensity across industries. The results are robust to including the industry dummies with stable coefficients.

Firm dummies are added in column (4), which controls for all firm-specific factors that affect import intensity across all years. The coefficient for electricity prices remains significant

at the 5% level but the coefficient is greatly reduced. The smaller coefficient for electricity price indicates it is the between-firm variation in electricity prices that explained most of the changes in import intensity in the earlier columns. Together, these results suggest that firms do respond to higher domestic electricity prices by increasing imports of intermediates, and that they shift the mix of imported intermediate inputs towards more electricity intense products.

A potential concern is that a change in the price of electricity that we observe is due to a demand shock at an aggregate level (the business cycle) or at the level of an individual firm. If higher firm-level demand leads to higher electricity prices this would weaken our argument that we are estimating causal effects of higher electricity prices on firm behavior. First, there is a negative correlation between firm size and the price they pay for electricity. Second, we argue that most firms our data are price takers on the electricity market.

## 8 Conclusions

The large increase in electricity prices experienced in Sweden after 2002 present an opportunity to study the impact of higher energy prices on imports. We develop a model of firms that choose to import intermediate inputs based on the price of electricity at home versus abroad. The model predicts that higher electricity prices encourage firms to source a greater share of their intermediate inputs from abroad. We test this prediction using detailed data on firm imports and the price they pay for electricity. The results suggest that Swedish firms responded to higher electricity prices by importing more electricity-intensive intermediate inputs.

We find that imports are an important coping mechanism for firms that face a domestic factor price increase. This is valuable insight for policymakers in countries where electricity supply is undergoing a major transformation and higher electricity prices are a possible outcome. In particular, the results highlight another aspect in the importance of free trade in intermediate imports.

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## 9 Appendix

The model in section 4 is fully solved. We present here the analytical solutions to the aggregate variables that characterize the equilibrium. The profits of type-D and type-M firms are

$$\begin{aligned}\pi(\varphi_i, 1) &= \frac{r_i}{\sigma} - f_m - f \\ \pi(\varphi_i, 0) &= \frac{r_i}{\sigma} - f\end{aligned}$$

respectively. Rewriting these expressions we get

$$\begin{aligned}\pi(\varphi_i, 1) &= B \left[ \frac{1}{\varphi_i \lambda_i} \right]^{1-\sigma} - f_t \\ \pi(\varphi_i, 0) &= B \left[ \frac{1}{\varphi_i \lambda_i} \right]^{1-\sigma} - f\end{aligned}$$

where  $B \equiv \frac{R}{\sigma} \left[ \frac{\sigma}{P(\sigma-1)\Gamma} \right]^{1-\sigma}$  and  $f_t \equiv f_m + f$ . Firms will not produce if their expected profits are negative. This means that type-D firms will be those with a productivity draw over the cutoff point at which profits are exactly equal to zero; This identifies the productivity cutoff for type-D firms

$$\varphi_D = \left( \frac{f}{B} \right)^{\frac{1}{\sigma-1}}.$$

Likewise, firms will not import intermediate inputs if the expected profit from doing so is negative. Hence, type-M firms will be those with a productivity draw over the cutoff point at which the profits of being an importer are exactly equal to zero. This identifies the productivity cutoff for type-M firms

$$\varphi_M = \frac{1}{\lambda_i} \left( \frac{f_t}{B} \right)^{\frac{1}{\sigma-1}}.$$

This implies the following condition

$$\frac{\varphi_M}{\varphi_D} = \left( \frac{f_t}{f} \right)^{\frac{1}{\sigma-1}} \frac{1}{\lambda_i} > 1$$

which is constrained to be greater than 1 to ensure that a necessary condition for becoming a type-M firm is that the productivity draw of the firm is greater than  $\varphi_D$ . The model is closed with the free entry condition

$$F = \int_{\varphi_M}^{\infty} \left( \frac{r_i^m}{\sigma} - f_m - f \right) dG(\varphi) + \int_{\varphi_D}^{\varphi_M} \left( \frac{r_i^d}{\sigma} - f \right) dG(\varphi) = \frac{R}{n\sigma}$$

The model yields analytical solutions for the productivity cutoffs and the price index assuming a Pareto distribution with a shape factor  $k$ . We impose the condition for convergence

and define  $\beta = k(\sigma - 1) > 0$ . This yields the explicit solution for the cutoff conditions

$$\varphi_D^{\beta(\sigma-1)} = \frac{n\sigma f}{\lambda_i^{\beta(\sigma-1)} R(\beta-1)} \left( \frac{f}{f_t} \right)^{\beta-1} \left( \beta \left( 1 - \frac{1}{\lambda_i^{\sigma-1}} \right) + \frac{1}{\lambda_i^{\beta(\sigma-1)}} \left( \frac{f_t}{f} \right)^{\beta-1} - \frac{f_m}{f_t} (\beta-1) \right)$$

$$\varphi_M^{\beta(\sigma-1)} = \frac{n\sigma f_t}{\lambda_i^{\beta(\sigma-1)} R(\beta-1)} \left( \beta \left( 1 - \frac{1}{\lambda_i^{\sigma-1}} \right) \lambda_i^{\beta(\sigma-1)} + \left( \frac{f_t}{f} \right)^{\beta-1} - \lambda_i^{\beta(\sigma-1)} \frac{f_m}{f_t} (\beta-1) \right)$$

for type-D and type-M firms respectively. The price index is obtained by integrating across firm productivities

$$P^{1-\sigma} = n \left( \frac{\sigma}{\Gamma(\sigma-1)} \right)^{1-\sigma} \int_{\varphi_D}^{\infty} \left( \frac{1}{\varphi_i \lambda_i} \right)^{1-\sigma} dG(\varphi_i | \varphi_D).$$

The explicit solution is

$$P^{1-\sigma} = n \left( \frac{\sigma}{\Gamma(\sigma-1)} \right)^{1-\sigma} \frac{\beta}{\beta-1} \left( \frac{f}{f_t} \right)^{\beta-1} \frac{\varphi_D^{\sigma-1}}{(\varphi_D^{\beta(\sigma-1)} - 1)} \left( \left( 1 - \frac{1}{\lambda_i^{(\sigma-1)}} \right) \lambda_i^{\beta(\sigma-1)} + \frac{1}{\lambda_i^{\beta(\sigma-1)}} \left( \frac{f_t}{f} \right)^{(\beta-1)} \right).$$