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Firm Productivity and Carbon Leakage: A Study of Swedish Manufacturing Firms

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Firm productivity and carbon leakage: A study of Swedish manufacturing firms *

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Abstract

This paper examines the intensive and extensive margins of carbon leakage. The analysis uses an increase in the Swedish electricity price to identify the impact on imports at the firm and product level. Our model of heterogenous firms predicts that higher domestic electricity prices lead firms to substitute towards imports of electricity-intense products. We test the predictions of the model using detailed firm-level data for Swedish manufacturing that includes the firm's electricity use, their electricity cost, and the products they import, over the years 2001-2006 inclusive. We find evidence that the impact of the electricity price is mostly a story about the extensive margin of firm imports: firms with a certain productivity respond to higher electricity prices by substituting towards relatively electricity-intense imported products. We do not find much support of an intensive margin effect, i.e. for the notion that an electricity price increase induces a broad response across firms in a given sector. Our empirical results identify the magnitude of the impact of the electricity price increase on imports and our findings characterize the firms that could be at risk to leakage.

JEL Classification Codes: D21, F18.

Keywords: Firm heterogeneity, carbon leakage, energy, importing.

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1 Introduction

There is rising concern that the integration of international markets, coupled with asymmetric energy prices across countries, are putting pressure on energy intense industries facing competition from abroad. The concern is amplified by the expectation that energy prices will become increasingly asymmetric if ambitious policy commitments are realized.[1] Increasing energy prices at home, it is argued, will lead to an increase in imports as production is relocated *offshore*, to areas with lower energy prices.

A principle source of the concern with offshoring is that it undermines national industrial interests (e.g. *competitiveness*) and compromises the effectiveness of policy designed to target externalities of a transboundary nature. Domestic climate change policy, for example, has the potential to increase domestic energy prices, and issues of competitiveness and leakage[2] are a prominent feature of international climate discussions. These concerns have helped spur a large environmental economics literature that examines these issues. At the same time, relatively few economic studies have focused on importing and there is a dearth of evidence on how firms and their engagement in international markets respond to higher domestic energy prices. As far as we know, *there has been no explicit consideration of the enormous and persistent productivity differences across producers within narrowly defined industries*, and how this affects the sourcing of inputs from abroad, and in turn what effect this might have for competitiveness and leakage concerns.

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 tractable analytical model of heterogeneous firms that incorporates firm demand for imports.

The theory yields predictions on the extensive and intensive margins of trade. On the extensive margin, the theory predicts that an increase in the domestic price of energy results in less productive firms engaging in the import of intermediate inputs

[1]For example, the Confederation of Swedish Enterprise, representing Swedish industrial interests, has reacted strongly to the EU's Framework for Climate and Energy Policies 2030, which seeks to reduce EU domestic greenhouse gas emissions by 40% below the 1990 level by 2030. Consider for example the potential impact on German and Japanese energy prices as Nuclear facilities are taken offline.

[2]Leakage is defined here as the increase in production (and pollution) abroad resulting from a policy applied at home.

and that this effect is increasing in the energy intensity of the imports. Likewise, on the intensive margin, the theory predicts that an increase in the domestic price of energy results in a relative increase in the use of imported intermediate inputs and that this increase is particularly large for energy intense imports. In other words, firms' incentive to source intermediates abroad is increasing in products that embody large amounts of electricity as a share of their value.

We find evidence that the impact of the electricity price is mostly a story about the extensive margin of firm imports: firms respond to higher electricity prices by substituting towards relatively electricity-intense imported products. The empirical evidence on the extensive margin follows the predictions of the theory, imports of firms with intermediate productivity are most responsive to domestic electricity prices. There is little empirical support for the intensive margin effect, that the electricity price affects imports across all firms engaged in importing. This pattern is robust to controlling for importing firms' own electricity intensity and capital intensity. When we explore the results at the sectoral level and find it is a handful of sectors that drive the shift towards importing electricity-intense products. We identify these sectors and quantify their response to the electricity price increase. These results identify the sectors that could be at risk to leakage from an electricity price increase.

We test the hypotheses derived from our theory with a rich data set covering Swedish manufacturing sectors over the period 2001-2006. During this time period the domestic price of electricity in Sweden for industrial consumers increased significantly after a long period of low and stable prices. Sweden had faced relatively low prices until 2002, but prices converged towards levels paid in Germany and the EU15[3] average from 2003 and onward. Importantly, firms hedge their exposure to changes in the electricity price: some firms engage in long-term contracts with electricity suppliers for example. This introduces significant cross-firm variation in Swedish electricity costs. Moreover, our data also provides information on the electricity-intensity of intermediate inputs. Our identification strategy therefore uses the variation in firm-level electricity costs and the variation in product-level electricity-intensity to estimate how imports respond at the firm level.

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

[3]The EU15 comprised the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom. In May 2004, ten additional countries joined the Union.

makes it possible to construct a 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 thereby identify the impact of the electricity price increase.

The paper continues with a description of the Swedish electricity market in Section 2 and Section 3 reviews the related literature. The theoretical model is presented in Section 4, and the data and descriptive statistics are discussed in Section 5. The empirical specification and results of the analysis are described in Section 6, with robustness checks discussed in Section 6.1 and sectoral regressions discussed in Section 6.2. Section 7 concludes.

2 The Swedish Electricity Market

In terms of per capita usage, Sweden is one of the most electricity intense economies with only Island, 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. In contrast, the U.S. has a per capita electricity use that is 10% lower than Sweden's, and the EU15 are on average 54% lower. In 2008, Swedish hydro-power met 47% of Swedish electricity demand whereas nuclear power met 42%. The remaining 11% were produced using fossil fuels and bio-fuels. Sweden participates in the Scandinavian electricity market, which helps even out electricity prices across the region.

Figure 1 illustrates that Swedish electricity prices prior to 2002 were low relative to continental Europe but increased in 2003, converging towards levels paid in Germany and the EU15 average price. Importantly for the analysis undertaken here, the price of electricity in Sweden increased relative to the price paid across. Sweden's major trading partners. This increase in Sweden's electricity price is a critical aspect of our identification strategy. Moreover, our identification strategy exploits the variation in electricity price across import origins. Sweden imports most from the other Scandinavian countries and the other members of the EU15. Moreover, Sweden's electricity price is correlated with the electricity price of neighboring countries, which are also Sweden's major trading partners. The other top five countries of origin are Russia, Chile, Poland, the US and China.

The change in Sweden's electricity price was driven by several factors. For one,

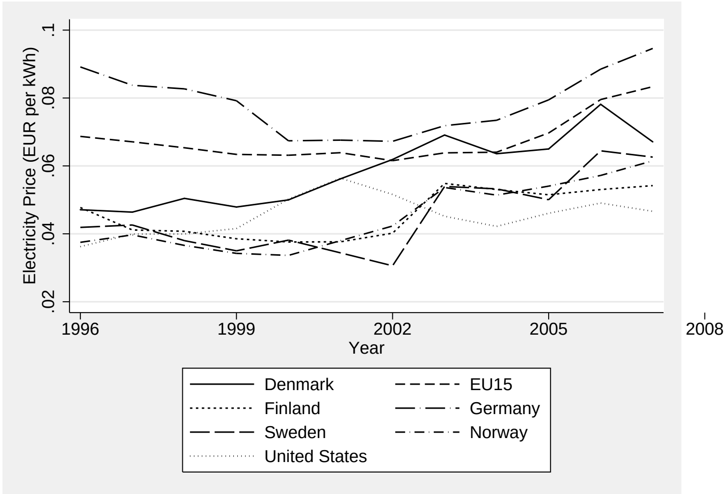

Figure 1: Average annual electricity nominal prices paid in Sweden and other countries. Source: Eurostat, U.S. Energy Information Administration.

electricity markets in Scandinavia have become more closely integrated with those of continental Europe, which led to a convergence in prices. Another factor was a particularly dry summer in 2002, which led to decreased hydro-power production and a spike in electricity prices in the winter of 2003. Levels in the hydro-power magazines did not return to normal until the end of 2004.

The launch of the European Union's Emission Trading system in 2005, a policy initiative to tackle emissions that cause climate change, likely had an impact on electricity prices across Europe. The introduction of tradeable emissions permits was intended to increase the cost of producing energy with greenhouse gas intense technology. Swedish electricity production is dominated by low emission technology, namely hydro-power 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, which restricted the supply of 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.[4] At the same time there is significant variation across each of these sectors,

[4]The next two most important sectors are basic metals with approximately 13-20%, and chem-

as well as within each sector, in terms of their electricity intensity.

Firms can, and do, manage the risk of electricity price changes by engaging in longer term contracts and hedging. Thus the electricity costs paid by many firms are distinct from the daily electricity spot price. The dramatic price spike in the inter-day electricity price at the end of 2002 (that saw electricity prices reach over 1 SEK/KWh) was likely mitigated, to varying degrees, by long-term contracts and futures hedging strategies deployed by firms. This variation in electricity price hedging is discussed later on.

Finally, during the 1998-2007 period, the Swedish economy grew steadily and this also played a role in determining the evolution of Swedish electricity prices. Swedish GDP grew at 2.5% in 2002, 2.3% in 2003 and 4.2% in 2004. Changes in demand are therefore also a key consideration when studying 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. There is, likewise, a sizable literature examining the economic impact of a change in the relative price of imports. The theory we develop extends the trade models of heterogeneous 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 (2013). 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 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

icals 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 NACE two digit level.

and importing. Unlike these studies, our model examines how imports are used by some firms to mitigate a domestic factor price increase. Thus the demand for imported intermediates is partly derived from "love of variety" in production as in Kasahara and Lapham (2013) but also from the change in the price of electricity at home relative to abroad.

Offshoring, has been studied in a neoclassical 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. However, in our study we are interested in the intensive and extensive margins of firm-level imports.

A change in the real 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 a real exchange rate shock Norwegian importers and exporters shed labor however only the exporters increased labor productivity according to Ekholm et al. (2012). 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 on the U.S.-Canada Iron Ore sector in the 1970's. In response to this shock, labor productivity in the sector doubled. In contrast to these studies, 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 electricity price. The economy consists of a monopolistic competitive industry (manufacturing) that is engaged in the production of differentiated goods, using intermediate inputs, under increasing returns. Firms engaged in the production of final goods are heterogeneous in productivity and face fixed importing costs, analogous to the fixed cost for exporting deployed by Melitz (2003). However, in our setting there is no exporting activity and this means there is an outside sector that balances trade: this is a partial equilibrium theory.

Consumer preferences over manufactured final goods are CES, following Dixit and Stiglitz

(1977). Consumers allocate revenue R across varieties $i \in \Omega$ to solve

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

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:

$$c_i = \frac{p_i^{-\sigma}}{P^{1-\sigma}} R, \tag{2}$$

where

$$P \equiv \left(\int_{i \in \Omega} p_i^{1-\sigma} di \right)^{\frac{1}{1-\sigma}} \tag{3}$$

is the price index of manufacturing goods.

The production side of the model is derived from Kasahara and Lapham (2013). In our set up, firms producing the final goods must pay a fixed cost F to enter the manufacturing sector. After having sunk F, the firm observes its own electricity efficiency coefficient φ_i drawn from a cumulative distribution $G(\varphi_i)$. Once firms observe their productivity[5] 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 inputs is undertaken in both domestic and foreign countries under perfect competition. Production follows a Cobb-Douglas technology that combines electricity e with some non-electric factor k to produce a quantity of intermediate inputs

$$x_j = e_j^{\delta} k_j^{1-\delta}, \tag{4}$$

where the subscript $j \in (d, f)$ denotes domestic and foreign respectively. δ captures

[5] The focus of the analysis is on how electricity is used in production. Insofar as the theory is concerned, the term electricity efficiency and productivity are synonymous.

the share of electricity used in production. Producers of the intermediate inputs pay a price ρ_j for e_j and 1 for the factor k_j. The cost minimization problem facing domestic and foreign firms is

$$\begin{aligned}
\min_{e_j,k_j} C\left(e_j,k_j\right) &= \rho_j e_j + k_j && (5)\\
\text{such that } 1 &= e_j^{\delta} k_j^{1-\delta} && (6)\\
\text{and } e_j &> 0, k_j > 0. && (7)
\end{aligned}$$

The solution yields p_{x_d} and p_{x_f}, which are the prices of each domestic and foreign intermediate variety, respectively. We express this as the ratio

$$\frac{p_{x_d}}{p_{x_f}} = \rho^{\delta}, \tag{8}$$

where $\rho \equiv \frac{\rho_d}{\rho_f}$. These intermediate goods are supplied to the firms producing the final good, which are denoted by subscript i. These firms employ intermediate varieties x_j in the production of a quantity of final good, denoted X. We assume a Cobb-Douglas technology that combines electricity l_i with intermediate inputs, while the quantities of domestic intermediate inputs $x_{d,i}$ and, for type-M firms, quantities of imported intermediate inputs $x_{f,i}$ are combined via a CES production function:

$$X\left(\varphi_i, m_i\right) = \varphi_i l_i^{\alpha}\left[\left(x_{d,i}\right)^{\frac{\gamma-1}{\gamma}} + m_i\left(x_{f,i}\right)^{\frac{\gamma-1}{\gamma}}\right]^{\frac{(1-\alpha)\gamma}{\gamma-1}}.$$

φ_i is a parameter capturing the productivity of firm i. Designate φ_i 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 between domestic and foreign intermediate inputs in production with a constant elasticity $\gamma > 1$: accessing foreign intermediate inputs augments total factor productivity. In this setting, the term *variety* refers to horizontally differentiated products.[6] $m_i = (0,1)$ 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 ε_i. $1-\alpha$ is therefore the

[6]This approach is also used by Kasahara and Lapham (2013) 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).

share of intermediate inputs used in the production of the final good.

The model is solved contingent on domestic and foreign electricity prices paid: a firm's cost minimization problem is solved taking the electricity prices as given. The problem facing the firm producing the final good is therefore

$$\min_{l_i, x_{j,i}} C(l_i, x_{d,i}, x_{f,i}) = \varepsilon_i l_i + p_{x_d} x_{d,i} + p_{x_f} x_{f,i} \tag{9}$$

$$\begin{aligned} \text{such that } 1 &= \varphi_i l_i^{\alpha} \left[(x_{d,i})^{\frac{\gamma-1}{\gamma}} + m_i (x_{f,i})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{(1-\alpha)\gamma}{\gamma-1}} \\ \text{and } l_i &> 0, x_{j,i} > 0. \end{aligned}$$

Cost minimization means that a type-M firm's demand for imported intermediates can be expressed as a function of the demand for domestic intermediates. The first order conditions of Equation (9), together with Equation (8), imply the following result:

$$\frac{x_{f,i}}{x_{d,i}} = \left(\frac{p_{x_d}}{p_{x_f}} \right)^{\gamma} = \rho^{\delta\gamma}, \tag{10}$$

Equation 10 shows that, relative to the demand for domestic varieties, the demand for imported intermediates increases in the relative price of domestic varieties. The relative price of domestic and foreign intermediate inputs is, in turn, a function of ρ, the relative electricity price paid by domestic and foreign intermediate firms as derived with Equation (8). The relative demand for imported intermediates is also increasing in both δ, the electricity intensity of intermediates inputs and γ, the decree to which foreign and intermediate varieties can be substituted for one another. Likewise, equilibrium demand for electricity by firm i is

$$l_i = x_d \rho^{\delta} \frac{\alpha}{\varepsilon_i (1-\alpha)} \left[1 + m_i \rho^{\delta(\gamma-1)} \right]. \tag{11}$$

A firm's output can therefore be expressed as

$$X(\varphi_i, m_i) = \varphi_i \lambda_i l_i^{\alpha} \left[\left(1 + m_i \rho^{\delta(\gamma-1)} \right) x_d \right]^{(1-\alpha)}. \tag{12}$$

Firm productivity can therefore be expressed as the product of a distribution of in-house productivity φ_i and a distribution of productivity enhancements from importing λ_i where

$$\lambda_i \equiv \left[1 + m_i \rho^{\delta(\gamma-1)} \right]^{\frac{1-\alpha}{\gamma-1}} \tag{13}$$

is a productivity enhancement term capturing two effects. The first is the productivity benefit of employing imported intermediate inputs: $\lambda_i = 1$ for type-D firms and $\lambda_i > 1$ for type-M firms. This is driven by the love of variety characteristic of firm i's production technology. The second is from a change in ρ suggesting that an increase in the relative price of domestic electricity leads to an increase in the benefit from using imported intermediates.

Having observed their productivity draws, 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 σ is therefore equal to the elasticity of substitution between any pair of differentiated goods. Firms set prices as a function of the their marginal cost

$$p_i = \frac{\sigma}{\sigma - 1} \frac{1}{\Gamma \varphi_i \lambda_i} \tag{14}$$

where $\Gamma \equiv \alpha^{\alpha} (1 - \alpha)^{1-\alpha}$. This pricing rule is analogous to Melitz (2003). Revenue for the firm is therefore

$$r_i = R \left[\frac{\sigma}{\sigma - 1} \frac{1}{P \Gamma \varphi_i \lambda_i} \right]^{1-\sigma} \tag{15}$$

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

$$\pi(\varphi_i, 0) = \frac{r_i}{\sigma} - f \tag{16}$$

$$\pi(\varphi_i, 1) = \frac{r_i}{\sigma} - f_m - f \tag{17}$$

respectively. Substituting Equation (15) into Equation (16) and Equation (17) yields

$$\pi(\varphi_i, 0) = B \left[\frac{1}{\varphi_i \lambda_i} \right]^{1-\sigma} - f, \tag{18}$$

$$\pi(\varphi_i, 1) = B \left[\frac{1}{\varphi_i \lambda_i} \right]^{1-\sigma} - f_m + f, \tag{19}$$

where $B \equiv \frac{R}{\sigma} \left[\frac{\sigma}{P(\sigma-1)\Gamma} \right]^{1-\sigma}$.

4.1 Extensive Margin Predictions

Assume the productivities of the manufacturing firms producing good i follow the Pareto distribution with $G(\varphi|\varphi_M) = (\varphi/\varphi_M)^k$ where k is the shape parameter. The model yields the solution for the productivity cutoffs for type-M firms.[7]

$$\varphi_M^{\beta(\sigma-1)} = \Theta_M \left[\beta \left(1 - \left(\frac{1}{\lambda_i} \right)^{\sigma-1} \right) + \left(\frac{f_m + f}{f} \right)^{\beta-1} \left(\frac{1}{\lambda_i} \right)^{\beta(\sigma-1)} - \frac{f_m}{f_m + f} \right], \quad (20)$$

where

$$\Theta_M \equiv \frac{1}{F} \left(\frac{f_m + f}{\beta - 1} \right) \quad (21)$$

and

$$\beta \equiv \frac{k}{(\sigma - 1)} > 1. \quad (22)$$

This expression describes the impact of an increase in the relative price of domestic electricity on the productivity cut-off for type-M firms. $\varphi_M^{\beta(\sigma-1)}$ is a function of the relative price of domestic to foreign electricity ρ, which enters here via λ_i only. In order to guide our empirical analysis we are interested in knowing (1) how the import cutoff changes as the relative price of domestically-produced electricity changes, i.e. $\partial\varphi_M^{\beta(\sigma-1)}/\partial\rho$, and (2) how the responsiveness of the cutoff to electricity prices varies for imports of high- versus low-electricity intense goods, i.e. $\partial^2\varphi_M^{\beta(\sigma-1)}/\partial\rho\partial\delta$. We summarize the results of these comparative statics in the following, empirically testable, proposition:

Proposition 1. *The productivity cut-off for type-M firms is falling in ρ. The productivity cut-off falls faster in ρ for more electricity-intense intermediate inputs, provided $\rho > 1$. Formally:*

$$\frac{\partial\varphi_M^{\beta(\sigma-1)}}{\partial\rho} < 0, \quad (23)$$

$$\frac{\partial^2\varphi_M^{\beta(\sigma-1)}}{\partial\rho\partial\delta} < 0 \quad if \quad \rho > 1. \quad (24)$$

When $\rho < 1$, $\partial^2\varphi_M^{\beta(\sigma-1)}/\partial\rho\partial\delta < 0$ holds provided

$$1 - \alpha < -\frac{1}{\rho^{\delta(\gamma-1)}} \left(\frac{1 + \rho^{\delta(\gamma-1)}}{\delta \ln \rho} + (\gamma - 1) \right)$$

[7] Closed form solutions for φ_D and P are provided in Appendix A.1.

Proof. See Appendix A.2. ■

The first part of Proposition 1 is straight forward: a higher relative price of electricity at home leads less productive firms to begin importing. The second part of Proposition 1 establishes the conditions under which the extensive margin of imports is more sensitive to highly electricity-intense imports. It is important to note that the sign of the cross derivative depends on ρ. The sign is unambiguously negative if the domestic electricity price is higher than the electricity price abroad, i.e $\rho > 1$. In this case, an increase in the electricity intensity of intermediates, δ, will induce less productive firms to start importing intermediates in response to an increase in ρ.

On the other hand, the sign is ambiguous when the domestic electricity price is lower than the electricity price abroad, i.e. $\rho < 1$. In this case, an increase in the electricity intensity of intermediate may or may not induce less productive firms to start importing intermediates in response to an increase in ρ. Formally, this is the case where $\partial^2 \varphi_M^{\beta(\sigma-1)} / \partial\rho\partial\delta > 0$. In some cases, increasing the electricity intensity of intermediates may not steepen the response of $\varphi_M^{\beta(\sigma-1)}$ to the electricity price increase.

This result suggests that firms start to source electricity intense intermediate inputs from abroad even when Sweden's electricity price is relatively low. The outcome depends on the relative productivity gain from importing versus the difference in the level of the electricity price at home and abroad, which is captured by the restriction on the parameter α.

4.2 Intensive Margin Predictions

Contingent on a firm i being type-M we derive an expression that describes firm demand for intermediate inputs. There is no international trade in final goods, hence demand for final good i must equal output from firm i. With this, obtain firm i's demand for domestic and imported intermediate inputs

$$x_d = \rho^{-\alpha\delta} \frac{(\lambda_i \varphi_i)^{\sigma-1}}{1 + m_i \rho^{\delta(\gamma-1)}} \frac{R}{\Theta_x P^{1-\sigma}} \tag{25}$$

$$x_f = \rho^{(\gamma-\alpha)\delta} \frac{(\lambda_i \varphi_i)^{\sigma-1}}{1 + m_i \rho^{\delta(\gamma-1)}} \frac{R}{\Theta_x P^{1-\sigma}} \tag{26}$$

where $\Theta_x \equiv \left(\frac{\sigma}{\Gamma(\sigma-1)}\right)^{\sigma} \left(\frac{\alpha}{(1-\alpha)}\right)^{\alpha}$.

A change in ρ affects firm level demand for imported intermediate inputs x_f in several ways. First is the direct reduction in cost resulting from avoided domestic electricity prices. This is captured by $\rho^{(\gamma-\alpha)\delta}$. 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 a productivity effect. Accessing foreign inputs increases productivity, which in turn drives down the demand for imports; the productivity benefits of variety are enhanced in ρ. This is captured by the denominator term $1 + m_i \rho^{\delta(\gamma-1)}$. Finally, a change in ρ 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 $\partial P^{1-\sigma}/\partial\rho > 0$.

Thus a domestic electricity price increase affects demand for the final good, drives an increase in the demand for imports, and at the same time enhances the productivity benefit of importing, which serves to decrease the demand for imports. A change in ρ can affect demand for x_f via several channels that can confound each other. We therefore derive our testable hypotheses for the intensive margin of imports from Equation (10), which we summarize with the following proposition:

Proposition 2. *Relative to a firm's demand for domestic intermediate inputs, demand for imported intermediates increases in ρ. The relative demand for a domestic intermediate input increases faster in ρ for a more electricity-intense intermediate input. Formally*

$$\frac{\partial \ln\left(\frac{x_{f,i}}{x_{d,i}}\right)}{\partial \ln \rho} = \delta\gamma > 0,$$

$$\frac{\partial^2 \ln\left(\frac{x_{f,i}}{x_{d,i}}\right)}{\partial \ln \rho \partial \delta} = \gamma > 0.$$

Proof. The first part of Proposition 2 follows direct from logging both sides of (10) and solving the derivative with respect to ρ. The second part of Proposition 2 follows from taking the second derivative with respect to δ. ■

A new result from this model is that it shows how an increase in the relative price of domestically sourced inputs, driven in this case by the price of electricity, induces less productive firms to source inputs from abroad. The impetus to substitute towards inputs from abroad is not only derived from the direct savings from cheaper foreign inputs, but through several channels. Equations 25 and 26 show how a change in ρ affects the demand for intermediate inputs directly, as well as via λ and $P^{1-sigma}$. This is an example of the particular challenges of identifying the impact of input price changes on importing activity. These results guide our approach to the data and our empirical strategy.

5 Data and Descriptive Statistics

The data is obtained from the Swedish Survey of Manufacturers conducted by Statistics Sweden, the Swedish government's statistical agency. We use data for 2001-2006, which covers 13298 firms (4-digit NACE Rev.1.1 codes 10.30-37.20) with 10 or more employees. The survey contains information on output, value-added, employment, capital stocks, investment and value of other primary factors of production 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. The customs data allows us to observe what firms are importing at the product level (at CN8), including country of origin.

The electricity data also comes from Statistics Sweden and includes the quantity and cost of electricity paid each year. The energy survey covers 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 costs across six electricity intense sectors, defined at the two-digit NACE level, are presented in Figure 2. The figure illustrates the significant variation in firm electricity cost, even within two-digit industry classifications.

Forward pricing contracts on the electricity futures market extend up to three years, which implies that an increasing share of firms would be exposed to higher costs by 2006, three years after the sharp increase in the domestic electricity price. Indeed, we observe that firm electricity cost increases lag the period over which electricity prices increased most. This is likely due to the of long-term electricity contracts. We therefore use the years 2001 through to 2006 inclusive for our regression analysis. Moreover, the opportunity cost of consuming electricity instead of selling it onwards is still the same regardless of whether firms have long-term contracts or firms take offsetting positions on the futures market.

Tariffs have also, understandably, played a role in determining firm demand for imported intermediate inputs. Therefore we control for changes in tariff rates imposed on imports. Sweden joined the European Union in 1995 and the tariffs have since then been set in Brussels. This mitigates, to a degree, the extent to which Swedish industry has exerted influence on tariff rates. Another consideration is that EU import tariffs for pulp and paper products were reduced in 2004 under

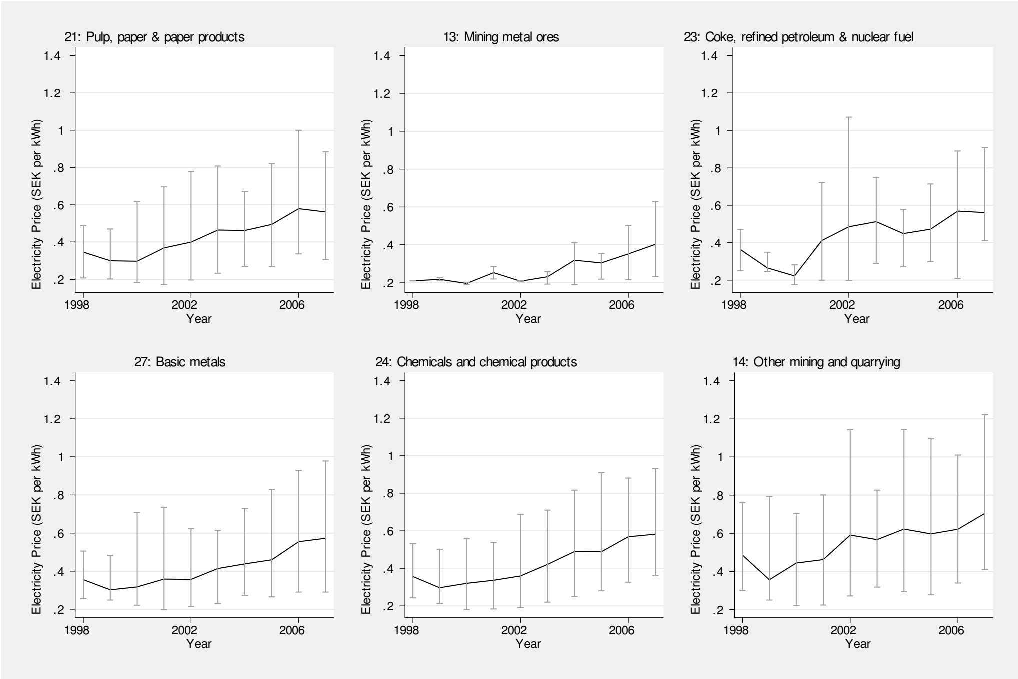

Figure 2: Electricity price distribution for six electricity intense sectors, by 2-digit NACE industry classification, showing the mean electricity price in SEK/KWh and the 5th and 95th percentile limits of the electricity prices paid by firms within the sector. Source: Statistics Sweden and authors' calculations

the Accelerated Tariff Liberalization initiative in forest products among members of the WTO. This is a particularly relevant consideration here as the Swedish pulp and paper sector is also the most electricity intense sector in Sweden. In the regression analysis we omit pulp and paper imports in order to ensure that our results are not being driven by trade liberalization in forest products, which occurred after a 2004. We match tariff data from UNCTAD TRAINS, which is at the six-digit HS level, to our firm level import data that is coded to six-digit CN. We create an average import tariff faced by each firm in each year of the data and for each product they import. Finally, the European Union expanded in 2004 with the accession of 10 countries: Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia. Imports from these countries are dropped from the analysis.

The correlation coefficients for electricity costs and other firm-level variables for 2001 and for the change between 2001 and 2006 are given in Tables 1 and 2 respectively.

The correlation coefficients in Table 1 indicate that electricity costs are negatively correlated with productivity and firm size as proxied by employees, raw materials

Table 1: Correlations[1], 2001

	Electricity Cost	Value import	Employees	Raw Materials	Output
Value import	-0.0551				
Employees	-0.0900*	0.7979*			
Raw materials	-0.0712*	0.9028*	0.8906*		
Output	-0.0582	0.8417*	0.8913*	0.9090*	
Productivity	-0.0352	0.0612*	0.1071*	0.0836*	0.0885*

[1] Based on firms included in the regression from column (2) of Table 5, *p¡0.01

Table 2: Correlations[1], 2006-2001 First Difference

	Electricity Cost	Value import	Employees	Raw Materials	Output
Value import	-0.0104				
Employees	-0.0102	-0.1174*			
Raw materials	-0.0255	0.4256*	0.3679*		
Output	-0.0294	0.4770*	0.1193*	0.5492*	
Productivity	-0.0369	0.0270	0.1250*	0.1945*	0.1941*

[1] Based on firms included in the regression from column (2) of Table 5, *p¡0.01

and output for the cross-section of firms. Import values are positively correlated with the size and productivity measures. The correlation coefficients in Table 2 suggest that electricity costs, productivity and firm size are also negatively correlated within firms over time, although this negative relationship is less robust. It is reassuring, however, that electricity costs and import values are negatively correlated with each other and statistically insignificant, since this weakens the possibility that a positive relationship between importing and electricity prices is spuriously driven by demand shocks that would lead simultaneously to greater import requirements and higher firm electricity costs.

6 Analysis

We test the theory using a panel regression that spans years 2001 and 2006 inclusive. The benchmark empirical specification tests the impact of the domestic electricity price increase on imports at the firm level:

$$\begin{aligned} \ln(SM_{it}) = \alpha_i + \Sigma_{r=1}^{4}\upsilon_r \ln(I_i) \times \ln(EP_{it}) \times Q_{2001}^{r} + \Sigma_{r=1}^{4}\omega_r (\ln I_i) \times Q_{2001}^{r} \\ + \Sigma_{r=1}^{4}\gamma_r \ln(EP_{it}) \times Q_{2001}^{r} + \upsilon_5 \tau_{it} + \epsilon_{it}. \qquad (27) \\ (28) \end{aligned}$$

The dependent variable is defined as

$$SM_{it} \equiv \frac{x_{f,it}}{x_{d,it}} \tag{29}$$

where $x_{f,it}$ is the value of all imported intermediate products by firm i in year t and $x_{d,it}$ is the value of all intermediate inputs and raw materials (excluding imports) used by firm i in year t. The structure of the dependent variable follows directly from Proposition 2: expressing imports relative to total input use controls for firm-specific demand shocks that would otherwise confound our results.

The first independent variable of interest is I_{it}, which captures the log of the electricity intensity of firm i's imports in year t. We define this variable in two steps. First, we derive a proxy for the opportunity cost to produce or buy the input domestically instead of importing from abroad. Hence, the share of electricity embodied in imported products is calculated from the share of electricity cost embodied in Swedish-manufactured products. We calculate this electricity using the average over the years 2000 and 2001. This yields the electricity intensity of each Swedish sector at the SNI 2002 5-digit level. In the second step, we match these product-level electricity intensities to each firm's imports by using the CN8-SNI 2002 concordance. This yields a measure of the electricity intensity for each product imported by each firm, which we denote

$$I_{ip,2000-2001} = \frac{E_{ip,2000-2001}}{x_{f,ip,2000-2001}}$$

where $E_{ip,2000-2001}$ is the cost of electricity embodied in the product p imported by firm i and $x_{f,ip,2000-2001}$ is the cost of the product p imported by firm i. The dependent variable, I_{it} is then calculated as the unweighted average over each firm's imported products.[8] Formally:

$$I_{it} \equiv \frac{1}{N_{it}} \times \sum_{p=1}^{N_{it}} I_{ip,2000-2001} \tag{30}$$

where N_{it} is defined as the number of products imported by firm i in year t. The five most electricity products are listed in Table 3. The descriptive statistics Table 4 illustrate that our measure of electricity intensity varies widely across firms. A consequence of this approach is that electricity intensity is fixed at the product level. Variation in the electricity intensity of a firm's imports from year to year is

[8] One could derive I_{it} as a weighted average over imports, however this would introduce $x_{f,it}$ on the right hand side of the regression specification, which would then confound the results, since $x_{f,it}$ is also used to define the dependent variable.

therefore due *only* to changes in the structure of a firm's imported product mix. This average can vary from year to year if firms' change the types of products they import.

Table 3: Sweden's most electricity intense imported intermediate inputs $I_{i,2000-2001}$

Electricity intensity[1]	SNI 2002 5-digit	Description
7.38%	14300	Mining of chemical and fertilizer minerals
7.31%	20203	Manufacture of fibreboard
6.50%	27510	Casting of iron
6.31%	26510	Manufacture of cement
6.27%	10302	Extraction and agglomeration of peat

[1] Electricity intensity is defined as the ratio of electricity value to total firm output.

The second dependent variable of interest is EP_{it}, the electricity cost paid by firm i in year t, calculated using the electricity bill and the quantity of electricity used by each firm in the given year. Our theory suggests that these effects are most pronounced for firms with a productivity just below φ_M: it is these firms that may start to engage in sourcing inputs from abroad with the electricity price increase.

However, theory does not say where the productivity threshold lies. The fixed cost of importing might be high enough so that the electricity price increase has no affect on the extensive margin. If there is an extensive margin effect, the use of quartile dummies would identify where the effect occurs. The dependent variables I_{it} and EP_{it} are interacted with four size quartile indicator variables Q^r_{2001}, which take the value of one when a firm belongs to productivity quartile r in 2001 and zero otherwise. For example, a positive υ_r identifies firms in quartile r that find it profitable to start importing more electricity intense products as the cost of electricity increases.

The change in the tariff over the period is defined as the average tariff over all the products it imports. Again, this average can vary from year to year if firms' change the types of products they import.

$$\tau_{it} \equiv \frac{1}{N_{it}} \times \sum_{p=1}^{N_{it}} \tau_{ipt} \tag{31}$$

Table 4 shows the regression variables vary considerably. The dependent variable SM_{ipt}, import intensity, varies widely across firms and is large with imports making

Table 4: Descriptive statistics

Variable	obs.	mean	std. dev.	min	max
I_p: elec. intensity, imported product	12372	0.009	0.007	0.000	0.074
EP_{it}: electricity price, annual average	12372	0.469	0.244	0.004	10.822
τ_{it}: average import tariff	12372	0.697	1.304	0.000	26.000
I_{it}^{output}: elec. intensity, firm's output	12372	0.0266	0.054	0.000	1.804
$I_{p,raw}$: Import Intensity, imported product, share of total raw materials	12372	0.022	0.028	0.000	0.997
k_{it}: capital intensity	12302	0.674	3.127	0.000	293.674
SM_{ipt}: Import Intensity:	12372	0.299	6.692	0.000	620.001

[1] Based on observations from column (2) of Table 5

30% of total materials use on average. Note that the ratio of imports to material inputs can exceed 1: some manufacturing firms rely heavily on imported inputs. The electricity intensity embodied in imported products, I_p, varies substantially across products with an average of 0.9 % and a maximum of 7.4 %. Likewise, annual average electricity prices, EP_{it}, equal 0.469 SEK per kWh during the period we study, with substantial variation across firms. Import tariffs vary substantially across firm, and are hence included as a control. [do we need to say something about exchange rate exposure?]

Propositions 1 and 2 suggest that firms will respond to the electricity price increase by increasing their imports and that this increase should be most significant for electricity intense imports. Moreover, the impact of the electricity price will not necessarily affect all firms, but will be most significant for firms that lie adjacent to the import productivity cut-off φ_M defined by Equation 20.

Table 5 presents the baseline regression results. Firms of all productivity levels are pooled in the regression presented in Column (1). With this we can examine the extent the electricity price increase affected the intensive margin of imports (Proposition (2)). We find that the electricity price increase does not have any significant *average* effect on import patterns. Moreover, the interaction between electricity prices and electricity intensity, $EP_{it} \times I_{it}$ is not statistically significant. Hence there is little support for the idea that an increasing domestic electricity price will result in an increase in imports across all firms. Interestingly however, we find that the electricity intensity of firms' imports has positive and statistically significant effect on the intensive margin of firms' imports. The point estimate suggests that a one percent increase in the electricity intensity of inputs is associated with a 0.398

percent increase in imports: firms that import electricity-intense goods tended to increase their imports the most over the period 2001-2006.

In column (2) of Table 5 we examine the effect of electricity intensity of inputs and electricity prices on imports by productivity quartile, an approach that allows us to test both Propositions (1) and (2).[9] The point estimates for $EP_{it} \times Q^2_{2001}$ and $EP_{it} \times I_{it} \times Q^2_{2001}$ are statistically significant at the 5 percent level. The significant result is in line with the theoretical prediction: it is imports by firms in the second productivity quartile that respond the most to increases in electricity prices, especially for imports of electricity-intense goods. Consider the predicted effect of a 20% increase in EP_{it} on a firm in the second productivity quartile that imports products with a relatively high electricity intensity of 5%. Compute the partial derivative of Equation 28 with respect to $lnEP_{it}$ for $Q^2_{2001} = 1$ to obtain

$$\frac{\partial \ln (SM_{it})}{\partial \ln (EP_{it})} = \upsilon_2 \ln (I_i) + \gamma_2 \tag{32}$$

The estimates from column (2) of Table 5 then imply that the firm's import intensity would increase by 15.1 %, hence a firm with an average import intensity would see an increase from $SM_{ipt} = 30\%$ to 34.5%. Finally, note that both regressions of Table 5 show that the tariff has the expected negative effect on imports and is statistically significant at the 1 percent level.

Thus Proposition 1 finds support from the results in column (2) of Table 5. The significant and positive estimate of υ_2 suggests that firms start to import more electricity intense products as the price of electricity increases: there is a marked substitution towards electricity intense imports, which is what Proposition 1 predicts.

A surprising result is the role that a firm's productivity plays in determining firm imports. The results for the average effects of electricity prices from column (1) were confounded by the underlying heterogeneity in responses across firms. The results in column (2) suggest that the response of firms to higher electricity prices varies widely and this variation can be understood by examining the response along the dimension of firm-level productivity. Considering firm-level productivity differences is therefore a key consideration in identifying firm-level import responses to a domestic electricity price increase.

[9] The impact of electricity prices and electricity intensity of firms in the lowest productivity quartile are captured by the terms EP_{it}, I_{it} and $EP_{it} \times I_{it}$, un-interacted with Q^r_{2001} in the table.

Table 5: The impact of electricity costs on firm-level imports[1]

Dependent variable: $lnSM_{it}$[2]	(1)	(2)
$lnEP_{it}$: electricity cost of firm	0.076	0.077
	(0.052)	(0.070)
lnI_{it}: elec. intensity firm imports	0.398	0.348
	(0.089)***	(0.217)
$lnEP_{it} \times lnI_{it}$	0.051	-0.030
	(0.072)	(0.083)
$lnEP_{it} \times Q^2_{2001}$		-0.063
		(0.154)**
$lnEP_{it} \times Q^3_{2001}$		0.209
		(0.221)
$lnEP_{it} \times Q^4_{2001}$		-0.086
		(0.148)
$lnEP_{it} \times lnI_{it} \times Q^2_{2001}$		0.490
		(0.218)**
$lnEP_{it} \times lnI_{it} \times Q^3_{2001}$		0.282
		(0.247)
$lnEP_{it} \times lnI_{it} \times Q^4_{2001}$		0.221
		(0.239)
$lnI_{it} \times Q^2_{2001}$		0.136
		(0.272)
$lnI_{it} \times Q^3_{2001}$		-0.213
		(0.303)
$lnI_{it} \times Q^4_{2001}$		0.090
		(0.276)
τ: firm's average tariff	-0.132	-0.125
	(0.023)***	(0.023)***
Observations	13833	12372
R^2	0.017	0.019

[1] * p¡0.10, ** p¡0.05, *** p¡0.01. Standard errors in parentheses, robust standard errors in all specifications. Pulp and paper imports excluded. Imports from countries that acceded to the EU in 2004 excluded. Only the coefficients that are a function of EP_{it} are reported. Constant included in all specifications but not reported.

[2] The dependent variable is the logged ratio of the value of imported intermediate inputs to total intermediate inputs by each firm.

6.1 Robustness

We first check the robustness of the baseline results to the inclusion of controls for firms' capital intensity and electricity intensity of their own production. We also use an alternative measure of electricity intensity of imported goods. The results are found to be robust across all specifications and are reported in Table 6. In column (1) we add a control for firms own electricity intensity in production, I_{it}^{output} in order to control for the possibility that Swedish firms may shrink production and thus imports due to high domestic electricity prices. As expected, we find that higher electricity prices reduce imports for firms that themselves intense users of electricity in their production process. However, our main results are robust to controlling for firms' electricity intensity. In column (2) we control for firms' capital intensity, k_{it}in order to ensure that our main results are not driven by the underlying capital intensity of firms. We find that capital intensity has a positive but statistically insignificant coefficient, which suggests that our results are not driven by underlying differences across firms in their capital intensity.

Our claim that we are estimating causal effects of higher electricity prices on firm behavior would be undermined if higher firm-level demand leads to higher electricity prices. The change in the price of electricity that we observe *could* be due to a demand shock at an aggregate level (the business cycle) or at the level of an individual firm. However, we maintain that this concern does not undermine our analysis. We have shown that there is a negative correlation between firm size and the price they pay for electricity both across firms in a given year and within firms over time, see Tables 1 and 2. Thus firms that grow the fastest seem to pay lower prices over time, which is not supportive of the alternative mechanism where demand shocks are positively correlated with electricity prices. Moreover, we argue that our focus on systematic differences in importing high- versus low-electricity intense goods and use of firm fixed effects effectively controls for firm-level shocks. Our measure of cross-product variation in the electricity intensity of imported products is set at pre-2001 levels and is thus not endogenous to changes in electricity prices by construction.

6.2 Sectoral regressions

We parse the sample by sector at the 2-digit level, defined by NACE Rev.1.1 and run the regressions for each sector. Sectors for which significant results were found are

Table 6: Robustness[1]

Dependent variable: SM_{it}[2] Electricity Intensity Measure:	(1) Share of Output	(2) Share of Output	(3) Share of Materials[3]
$lnEP_{it}$: electricity cost of firm	0.110	0.089	0.052
	(0.071)	(0.070)	(0.307)
lnI_{it}: elec. intensity firm imports	0.368	0.342	0.395
	(0.217)*	(0.216)	(0.180)**
$lnEP_{it} \times lnI_{it}$	-0.213	-0.263	-0.040
	(0.186)	(0.188)	(0.082)
$lnEP_{it} \times Q^2_{2001}$	-0.053	-0.070	0.106
	(0.159)	(0.155)	(0.082)
$EP_{it} \times Q^3_{2001}$	0.224	0.191	0.469
	(0.223)	(0.223)	(0.308)
$EP_{it} \times Q^4_{2001}$	-0.108	-0.094	-0.217
	(0.158)	(0.146)	(0.101)**
$EP_{it} \times I_{it} \times Q^2_{2001}$	0.478	0.518	0.106
	(0.217)**	(0.219)**	(0.043)**
$EP_{it} \times I_{it} \times Q^3_{2001}$	0.272	0.309	0.091
	(0.246)	(0.249)	(0.053)*
$EP_{it} \times I_{it} \times Q^4_{2001}$	0.202	0.248	0.001
	(0.238)	(0.240)	(0.040)
$I_{it} \times Q^2_{2001}$	0.124	0.133	-0.059
	(0.272)	(0.272)	(0.222)
$I_{it} \times Q^3_{2001}$	-0.226	-0.206	-0.329
	(0.303)	(0.303)	(0.231)
$I_{it} \times Q^4_{2001}$	0.070	0.098	-0.076
	(0.276)	(0.275)	(0.209)
τ: firm's average tariff	-0.125	-0.128	-0.124
	(0.023)***	(0.024)***	(0.024)***
I^{output}_{it}: elec. intensity, firm's output	0.108		
	(0.042)**		
k_{it}: firm capital intensity		0.043	
		(0.040)	
Observations	12372	12302	12372
R^2	0.020	0.020	0.017

[1] * p¡0.10, ** p¡0.05, *** p¡0.01. Standard errors in parentheses, clustered at firm-level in all specifications. Pulp and paper imports excluded. 5-digit industry fixed effects used in all specifications. Constant included in all specifications but not reported.

[2] The dependent variable is the logged ratio of the value of imported intermediate inputs to total intermediate inputs by each firm.

[3] Electricity intensity in column (3) is calculated as electricity's share of total raw materials used to produce the good.

presented in Table 7. Sectors where no significant results were found are ommitted.[10]

There are eight sectors that follow the predictions of our theory; 10, 13, 14 Mining; 18 Apparel; 20 Wood Products; 22 Publishing; 28 Metal Products; and 35 Other transport equipment. All of these sectors saw an increase in import intensity with the electricity price increase.[11] For example, consider the impact of the electricity price increase on imports by the mining sectors. [12] The significant results are within the fourth productivity quartile and suggest a large impact of the electricity price increase. To interpret the results, consider a mining firm importing products with an electricity intensity of 1.13%, the average for these three sectors. A 20% increase in the price of electricity would result in a 38% increase in the firm's import intensity.

There are four sectors with significant results that surprisingly do not follow theory. It is surprising in that these sectors import a relatively large amount of embedded electricity. These sectors are: 27 Basic metals; 32 Communications equipment; 34 Motor vehicles; and 36 Furniture. In these sectors, the electricity price increase led to a fall in the import intensity. This is a rather intriguing result. Taken together, the sectoral regressions reveal that the impact of the electricity price increase varies significantly from one sector to the next. Moreover, within a given sector, a firm's productivity determines the pattern of import intensity.

[10] The sectors where no significant results were found include: 15 Manufacture of food products and beverages; 17 Manufacture of textiles; 24 Manufacture of chemicals and chemical products; 25 Manufacture of rubber and plastic products 26 Manufacture of other non-metallic mineral products; 29 Manufacture of machinery and equipment n.e.c.; 30 Manufacture of office machinery and computers; 31 Manufacture of electrical machinery and apparatus n.e.c; 33 Manufacture of medical, precision and optical instruments, watches and clocks; and 37 Recycling.

[11] Two of the sectors have too few observations. Sectors 19 and 23 include less than 11 firms.

[12] NACE Rev.1.1 code 10 Mining of coal and lignite; extraction of peat, 13 Mining of metal ores and 14 Other mining and quarrying

Table 7: Regression results by 2-digit NACE Rev.1.1.[1] The dependent variable for all specifications is SM_{it}[2]

Sector[3]	10,13,14 Mining	18 Apparel	19 Tanning	20 Wood Products	22 Publishing	23 Coke, petroleum	27 Basic metals	28 Metal products	32 Comm. equip.	34 Motor vehicles	35 Other transport equip.	36 Furniture
EP_{it}	-1.312	-1.058	-1.880	-0.253	-0.709	1.318	-0.681	-0.163	0.865	0.312	-0.053	0.100
	(2.702)	(0.932)	(1.623)	(0.446)	(0.685)	(2.109)	(0.394)*	(0.278)	(1.134)	(0.462)	(0.593)	(0.256)
I_{it}	-5.420	-2.898	-0.139	-0.727	0.455	-1.006	2.001	0.169	2.415	0.849	-1.141	0.418
	(2.747)*	(1.755)	(3.205)	(1.291)	(1.730)	(2.148)	(0.662)***	(0.450)	(0.990)**	(1.111)	(1.309)	(0.647)
$EP_{it} \times I_{it}$	-5.462	-3.741	-1.625	-0.583	0.184	-4.580	0.669	-0.427	1.349	1.793	0.144	0.330
	(3.456)	(2.357)	(4.797)	(0.856)	(0.462)	(5.313)	(0.532)	(0.489)	(0.716)*	(0.684)***	(1.119)	(0.604)
$EP_{it} \times Q^2_{2001}$	0.000	0.000	8.771	6.608	-1.054	9.259	1.529	-0.382	0.000	0.254	2.598	-3.643
	(.)	(.)	(2.911)***	(5.251)	(1.731)	(3.332)**	(3.077)	(0.793)	(.)	(1.160)	(2.953)	(2.115)*
$EP_{it} \times Q^3_{2001}$	6.527	4.465	3.717	1.130	0.660	-9.215	0.000	0.055	-18.212	-0.056	9.897	2.558
	(8.570)	(2.372)*	(3.559)	(0.315)***	(1.617)	(5.874)	(.)	(0.373)	(2.907)***	(1.136)	(6.281)	(1.631)
$EP_{it} \times Q^4_{2001}$	-1.895	-1.243	15.006	-0.088	3.006	40.999	1.982	-0.078	1.921	0.946	0.826	0.628
	(7.868)	(2.405)	(9.367)	(1.227)	(1.725)*	(6.418)***	(1.613)	(0.765)	(2.081)	(0.522)*	(1.470)	(0.518)
$EP_{it} \times I_{it} \times Q^2_{2001}$	0.942	0.000	18.538	-0.553	0.261	-0.747	-3.732	1.292	0.000	-0.950	2.614	-4.258
	(2.008)	(.)	(19.547)	(2.831)	(1.112)	(7.441)	(1.599)**	(0.781)*	(.)	(0.782)	(2.441)	(2.540)*
$EP_{it} \times I_{it} \times Q^3_{2001}$	4.596	4.095	0.448	-0.322	-0.968	7.912	0.479	0.424	0.000	-1.900	4.739	-3.345
	(2.722)	(2.376)*	(6.888)	(1.671)	(1.229)	(5.440)	(0.816)	(0.701)	(.)	(0.974)*	(2.785)*	(0.790)***
$EP_{it} \times I_{it} \times Q^4_{2001}$	11.568	1.256	4.265	0.770	0.356	-47.580	-0.317	0.804	0.443	1.030	-1.083	0.014
	(3.827)***	(2.654)	(5.790)	(1.404)	(1.107)	(4.638)***	(0.817)	(0.625)	(0.808)	(1.279)	(1.564)	(0.882)
$I_{it} \times Q^2_{2001}$	0.000	-2.222	18.435	1.074	-0.124	-1.632	-4.075	0.111	-44.349	0.216	3.529	-5.462
	(.)	(1.150)*	(12.654)	(2.223)	(1.940)	(4.619)	(1.551)***	(0.685)	(2.354)***	(1.481)	(2.754)	(2.183)**
$I_{it} \times Q^3_{2001}$	4.725	2.861	-3.867	-0.121	-1.483	5.907	2.844	0.609	3.589	-0.943	4.672	2.710
	(2.254)**	(2.107)	(5.549)	(1.848)	(2.110)	(3.423)	(0.764)***	(0.793)	(0.875)***	(1.351)	(4.928)	(3.760)
$I_{it} \times Q^4_{2001}$	10.576	1.142	-0.786	1.339	0.508	-51.606	-1.242	0.859	-0.005	0.801	0.857	-0.037
	(3.146)***	(2.190)	(4.381)	(1.669)	(2.064)	(0.676)***	(1.198)	(0.615)	(1.135)	(1.400)	(1.616)	(0.913)
τ	0.387	-0.061	0.088	-0.202	-0.061	0.006	-0.057	-0.176	-0.110	-0.137	0.109	-0.021
	(0.324)	(0.074)	(0.104)	(0.092)**	(0.049)	(0.192)	(0.051)	(0.059)***	(0.412)	(0.107)	(0.140)	(0.115)
Observations	82	80	56	772	408	53	519	1854	223	635	288	736
R^2	0.158	0.248	0.549	0.056	0.047	0.281	0.154	0.044	0.177	0.031	0.071	0.020

[1] * p¡0.10, ** p¡0.05, *** p¡0.01. Standard errors in parentheses, clustered at firm-level in all specifications. Pulp and paper imports excluded. 5-digit industry fixed effects used in all specifications.
[2] The dependent variable is the logged ratio of the value of imported intermediate inputs to total intermediate inputs by each firm.
[3] Sectors defined according to 2-digit NACE Rev.1.1.

7 Conclusions

The 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 heterogeneous 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 less productivity firms to begin importing intermediate inputs, and especially inputs that are electricity-intense.

A main point of this paper is that productivity differences between firms plays a critical role in determining how firms source imports on international markets. At the same time, this paper does not seek to quantify the total leakage that would result from an electricity price increase. Leakage occurs through a number of channels, our theory examines only the substitution between domestic and foreign intermediate inputs.

Our findings suggest two immediate implications for policy. The first is that the European Union's climate policies for Carbon Leakage have by and large considered the issue on a sector by sector basis and have neglected the enormous and persistent productivity differences between firms within even narrowly defined sectors. To date, the EU grants exceptions to climate policy on a sectoral basis in an effort to mitigate leakage effects. Some consideration of firm level productivity in determining the risk of leakage might help improve the effectiveness of the EU's climate policies. The same applies to discussions of US proposals to mitigate leakage. A second implication of our work is that importing inputs isn't only detrimental but can help firms cope with a domestic factor price increase, a valuable insight for policymakers in countries where electricity supply is undergoing a major transformation.

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Appendix

A.1 Solving the Productivity Cutoffs and Price Index

We present here the analytical solutions for the importer cutoff productivity (Equation 20) and the price index. Setting profits equal to zero in Equation 18 and rearranging yields an expression for the productivity of the firm that is indifferent between remaining a type-D firm and shutting down:

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

Likewise, the productivity cutoff for type-M firms is found by setting profits equal to zero in 19 and rearranging:

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

We combine these two cutoff equations to obtain the following parameter restriction:

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

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 φ_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

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

$$\varphi_M^{\beta(\sigma-1)} = \frac{1}{F}\left(\frac{f_m+f}{\beta-1}\right)\Theta$$

for type-D and type-M firms respectively where

$$\Theta \equiv \left[\beta\left(1-\left(\frac{1}{\lambda_i}\right)^{\sigma-1}\right)+\left(\frac{f_m+f}{f}\right)^{\beta-1}\left(\frac{1}{\lambda_i}\right)^{\beta(\sigma-1)}-\frac{f_m}{f_m+f}\right]$$

The price index is obtained by integrating across firm productivity

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

The explicit solution is

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

where

$$\Lambda \equiv \left(\left(1-\frac{1}{\lambda_i^{(\sigma-1)}}\right)\lambda_i^{\beta(\sigma-1)}+\frac{1}{\lambda_i^{\beta(\sigma-1)}}\left(\frac{f_m+f}{f}\right)^{(\beta-1)}\right)$$

A.2 Proof of Proposition (1)

First we show that $\partial\varphi_M^{\beta(\sigma-1)}/\partial\rho<0$. The sign of the impact of a change in $\frac{\rho_d}{\rho_f}$ on φ_M is derived as

$$\frac{\partial\varphi_M^{\beta(\sigma-1)}}{\partial\rho}=\frac{\partial\varphi_M^{\beta(\sigma-1)}}{\partial\lambda_i}\frac{\partial\lambda_i}{\partial\rho}. \tag{33}$$

It is enough to examine $\frac{\partial\varphi_M^{\beta(\sigma-1)}}{\partial\lambda_i}$ alone since $\frac{\partial\lambda_i}{\partial\rho}>0$ by Equation (13). Moreover $\frac{\partial\varphi_M^{\beta(\sigma-1)}}{\partial\lambda_i}$ is in fact strictly negative. This is derived from

$$\frac{\partial\varphi_M^{\beta(\sigma-1)}}{\partial\lambda_i}=\frac{\beta(\sigma-1)}{\beta-1}\left(\frac{f_m+f}{F}\right)\left[\frac{1}{\lambda_i^{\sigma}}-\frac{1}{\lambda_i^{\beta(\sigma-1)+1}}\left(\frac{f_m+f}{f}\right)^{\beta-1}\right], \tag{34}$$

and by the assumption that only active firms can be importers:

$$\frac{\varphi_M}{\varphi_D}>1. \tag{35}$$

Together, these conditions suggest

$$\frac{\partial\varphi_M^{\beta(\sigma-1)}}{\partial\rho}<0. \tag{36}$$

Second, we show the conditions under which $\partial^2 \varphi_M^{\beta(\sigma-1)}/\partial\rho\partial\delta < 0$. Formally this is derived by noting first that $\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i}$ is a function of δ via λ_i alone, hence

$$\frac{\partial}{\partial \delta} \frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \rho} = \overbrace{\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i}}^{negative} \frac{\partial^2 \lambda_i}{\partial \delta \partial \rho},$$

where $\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i} < 0$ by Proposition (1). What remains to characterize is the second term, which is:

$$\frac{\partial^2 \lambda_i}{\partial \delta \partial \rho} = \left(1 + \delta\left(1-\alpha\right)\ln\rho\left(\frac{\frac{(\gamma-1)}{(1-\alpha)} + \rho^{\delta(\gamma-1)}}{1+\rho^{\delta(\gamma-1)}}\right)\right)\overbrace{\frac{\left(1-\alpha\right)\lambda_i \rho^{\delta(\gamma-1)}}{\rho\left(1+\rho^{\delta(\gamma-1)}\right)}}^{positive}$$

and the sign depends on

$$sign\left[\frac{\partial^2 \lambda_i}{\partial \delta \partial \rho}\right] = sign\left(1 + \delta\left(1-\alpha\right)\ln\rho\left(\frac{\frac{(\gamma-1)}{(1-\alpha)} + \rho^{\delta(\gamma-1)}}{1+\rho^{\delta(\gamma-1)}}\right)\right)$$

which is the condition described in Proposition (1).